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**EDWIN B. STEEN
ASHLEY MONTAGU**

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Volume 2: Urinary, Respiratory, and
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ANATOMY and PHYSIOLOGY

Volume 2: Urinary, Respiratory, and
Nervous Systems, Sensations
and Sense Organs, Endocrine
and Reproductive Systems

Edwin B. Steen, Ph.D.

Ashley Montagu, Ph.D.



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Third Printing, 1961

L. C. Catalogue Card Number: 59-11857

Printed in the United States of America

PREFACE

This book is designed to meet the needs of students and others who wish to learn or review the essentials of human anatomy and physiology. It provides a comprehensive summary for students of the biological sciences, nursing, occupational therapy, and physical education. It should be most helpful to medical and dental students at all stages of their education—undergraduate, graduate, and post-graduate.

Since the authors have for many years taught all the groups of students mentioned above, they are acutely aware of the fact that in this field of study there is no satisfactory substitute for work in the laboratory. No one can acquire a thorough, functional knowledge of anatomy and physiology by merely reading a book. Consequently, this volume is not intended as a substitute for laboratory research but rather as a supplement to it, as a remembrancer following laboratory work, and, finally, as a refresher of the memory long after introductory studies of the subject have been concluded.

The Outline constitutes a completely integrated textbook of anatomy and physiology, covering the fundamentals of these inextricably intertwined subjects. The reader is asked to bear in mind always that anatomic structure and physiological function are but different aspects of the same thing, just as physics and chemistry are but two different ways of looking at matter. Anatomy and physiology are the names we give to two ways in which we look at organic matter, structure being a function of function, and function being a function of structure. There is rarely a structure without function and no function without structure, the two being inseparably associated.

For additional study aids, the reader is referred to the following companion volumes published by Barnes and Noble, Inc.:

Frohse, Brödel, and Schlossberg: *Atlas of Human Anatomy*

Tokay: *Fundamentals of Physiology*

Alexander: *General Biology*

Bryan and Bryan: *Bacteriology*

In a work of this kind, accuracy is an indispensable requirement. The authors have done everything in their power to make the text as accurate and as reliable as possible. The work has been critically read as a whole or in part by Dr. C.C. Boyer, of West Virginia University; Dr. E. S. Nasset, of the Rochester University School of Medicine; and Dr. Thane Robinson, of Western Michigan University. We are grate-

ful to these colleagues for their comments and suggestions. Dr. Samuel Smith, editor of Barnes and Noble, Inc., has at every stage been our most kindly and helpful mentor. We are deeply grateful to him. To Miss Harriet Meiss, editorial assistant of Barnes and Noble, Inc., and to Mr. George Cantzlaar, their consulting editor, we are indebted for constant assistance in the preparation of the manuscript. To Mr. Albert W. Janson and Mrs. G. H. Lahr for preparation of numerous illustrations, we express our appreciation. Finally, it remains to be said that seldom can two authors have enjoyed working together as have the present collaborators.

EDWIN B. STEEN
ASHLEY MONTAGU

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NOTE TO THE READER

The Tabulated Bibliography and Quick Reference Table on the following pages are valuable study aids. They make it possible to compare the discussion of any major topic in anatomy and physiology with the treatment of the same topic in widely used standard textbooks. The reader can thus obtain a summary or preview of a topic in this volume and then study the same information presented somewhat differently in a selected textbook. He can also study a topic in any of the listed textbooks and then review the same topic in this volume. Systematic use of this cross-reference system may thus contribute to a clear understanding of the subject.

TABULATED BIBLIOGRAPHY OF STANDARD TEXTBOOKS

This *College Outline* is keyed to standard textbooks in two ways.

1. If you are studying one of the following textbooks, consult the cross references here listed to find which pages of the *Outline* summarize the appropriate chapter of your text. (Roman numerals refer to textbook chapters, Arabic figures in parentheses to the corresponding *Outline* pages.)

2. If you are using the *Outline* as your basis for study and need further explanation of a topic, consult the pages of any of the standard textbooks as indicated in the Quick Reference Table on pages xiv-xv.

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Volume 2: Urinary, Respiratory, and
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and Sense Organs, Endocrine
and Reproductive Systems

INTRODUCTORY NOTE

The following special terms should be thoroughly understood inasmuch as they are used repeatedly in the study of anatomy.

| | |
|--------------------------------------|---|
| <i>Anterior</i> | toward the front of the body |
| <i>Posterior</i> | toward the back of the body |
| <i>Ventral</i> | toward the anterior side |
| <i>Dorsal</i> | toward the posterior side |
| <i>Superior</i> | above, upper |
| <i>Inferior</i> | below, lower |
| <i>Superficial</i> | on or near the surface |
| <i>Deep</i> | remote from the surface |
| <i>Internal</i> | within, inside |
| <i>External</i> | without, outside |
| <i>Proximal</i> | nearest to the body or some other center; nearest to the point of attachment |
| <i>Distal</i> | farthest from the body or some other center; farthest from the point of attachment |
| <i>Medial</i> | toward the medial plane of the body |
| <i>Lateral</i> | away from the medial plane of the body |
| <i>Craniad</i> | toward the cranium |
| <i>Cephalad</i> | toward the head end |
| <i>Mesiad</i> | toward the midline |
| <i>Caudad</i> | toward the tail end, away from the head |
| <i>Laterad</i> | toward the side, away from the midline |
| <i>Sagittal</i> | a vertical cut dividing the body into right and left portions |
| <i>Midsagittal</i> | a sagittal section dividing the body into halves |
| <i>Transverse</i> or <i>Cross</i> | a cut made at right angles to the long axis of the body, dividing the body into upper and lower portions |
| <i>Coronal</i> | a vertical cut made at right angles to the sagittal plane, dividing the body into anterior and posterior portions |

The last four terms can also be applied to individual organs or structures. In this sense, the axis of the organ (not the axis of the whole body) is the basis of description. Frequently, therefore, in discussions of the body as a whole, "longitudinal" is substituted for "sagittal," and "median longitudinal" for "midsagittal."

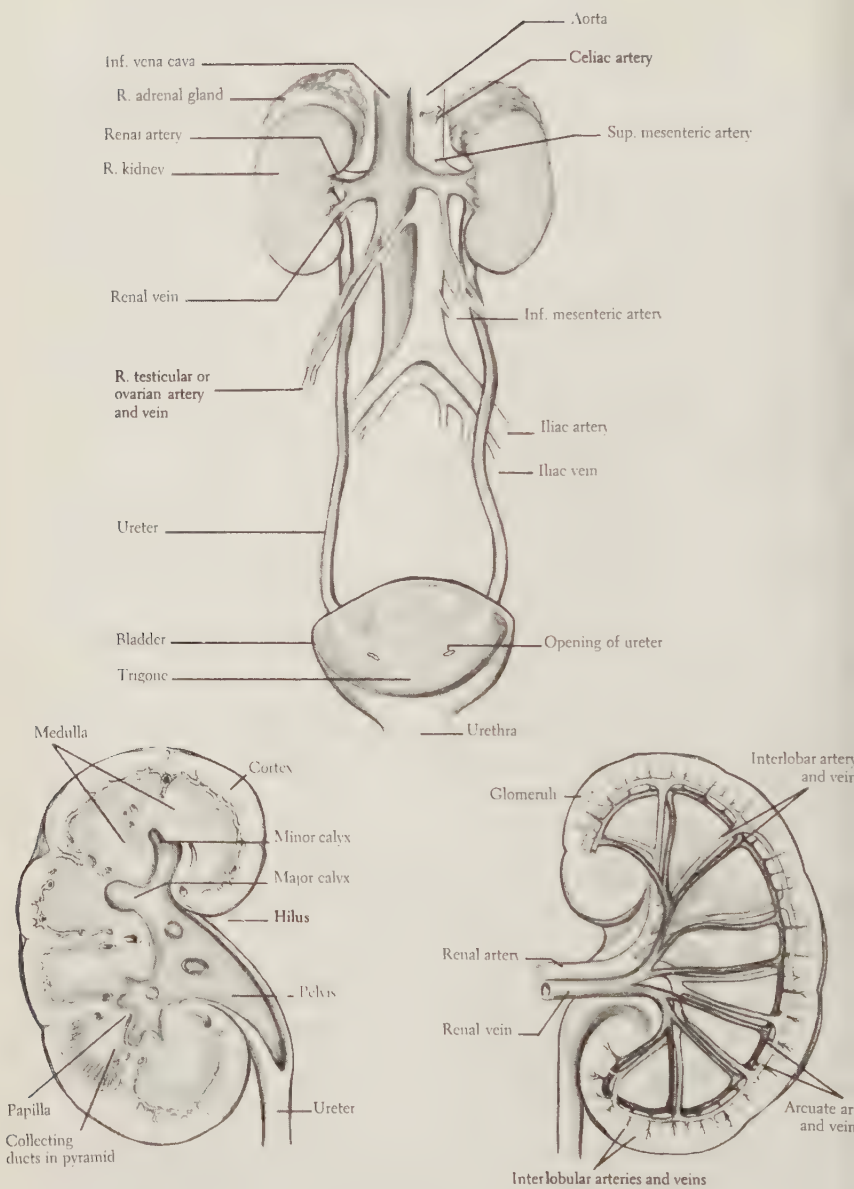


Fig. 1-1. The urinary system and a longitudinal section of the human kidney, showing its internal structure.

1: THE URINARY SYSTEM

The urinary system comprises the organs which are concerned with the production and elimination of urine, the fluid vehicle for the discharge of waste products from the body. Consisting of the kidneys, the urinary bladder, and the excretory passages (ureters and urethra), the urinary system acts in conjunction with the other organs of excretion (lungs, skin, intestines) to *maintain a constant internal environment* for the cells of the body. To this end, the following *functions* are performed:

1. Excretion of toxic substances and waste products of metabolism, in particular nitrogenous substances.
2. Maintenance of proper water balance in the body.
3. Maintenance of proper concentration of salts and other substances in the blood.
4. Maintenance of proper acid-base equilibrium in body fluids.

STRUCTURE OF THE URINARY SYSTEM

In the following description of the structure of the urinary system, the organs are presented in sequence: from the kidney, where urine is manufactured, to the urethra, from which it is finally passed out of the body.

Structure of the Kidney. The kidneys are paired organs, each lying lateral to the vertebral column against the posterior wall of the abdominal cavity at about the level of the last thoracic and the upper two lumbar vertebrae. The right kidney lies slightly lower than does the left. Each is approximately 11 to 12 cm. long, 5 to 7 cm. wide, and 3 cm. thick, and each is enclosed in a thin, fibrous *capsule*. The kidneys are retroperitoneal; that is, they lie behind the peritoneum. They are usually embedded in a mass of fat.

On the medial side of each kidney is an indentation, the *hilus*. At this point, blood and lymph vessels and nerves connect, and the ureter emerges from the kidney. The hilus opens into a slightly larger space, the *renal sinus*, which is surrounded by kidney tissue and is occupied principally by the *renal pelvis* and *renal calyces* (*sing.*, calyx).

In a longitudinal section, the kidney can be seen to consist of two general regions: a *cortex* or cortical region, and a *medulla*. The cortex forms the outermost layer and at intervals continues into the medulla as *columns of Bertini* or *renal columns*. It consists of regions composed

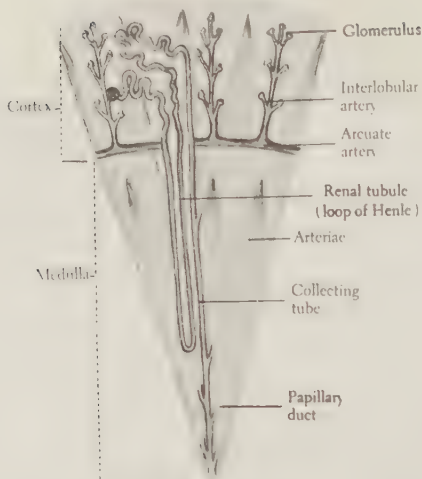


Fig. 1-2. Renal pyramid.

of straight tubules (*medullary rays*) alternating with regions consisting of glomeruli and convoluted tubules. The medulla consists of 8 to 18 cone-shaped structures called *pyramids*. The base of each pyramid is adjacent to the cortex; the free end or apex forms a *papilla* which projects centrally into a minor calyx. Two or three pyramids may terminate in a single papilla. At the tip of each pyramid are 10 to 25 minute openings of the *papillary ducts*.

In the central portion of the kidney is a cavity, the *renal pelvis*, which constitutes the expanded end of the ureter. The pelvis is divided into two or three portions, the *major calyces*, each being subdivided into four to six *minor calyces*. Each minor calyx encloses the apical end of one or more pyramids.

NEPHRON. The structural and functional unit of the kidney is the *nephron*, which consists of the renal corpuscle (*corpuscle of Malpighi*) and the *renal tubule*. There are a million or more nephrons in each kidney.

Renal Corpuscle. The corpuscle of Malpighi is a spheroidal body consisting of a glomerulus and the glomerular capsule (*Bowman's capsule*) which encloses it; the capsule is structurally a part of the tubule. The *glomerulus* consists of several looped capillary vessels which connect an afferent arteriole through which blood enters with the efferent arteriole through which blood leaves. The diameter of the afferent vessel is slightly larger than that of the efferent.

Renal Tubule. Each renal tubule consists of the following parts: a capsule, a proximal convoluted portion, the loop of Henle, and a distal convoluted portion.

The *capsule* of the renal tubule is the expanded end which, as Bowman's capsule, encloses the glomerulus. It is a double-walled, cup-like structure, the walls consisting of very thin squamous epithelium. The outer layer of the cup forms the *parietal layer*. At the point where the afferent and efferent vessels enter and leave the glomerulus, this layer is reflected over the glomerulus, which it invests closely to form the *visceral layer* or glomerular epithelium.

The *proximal convoluted portion*, which is continuous with the capsule, averages 14 mm. in length and 60 microns in diameter. It follows a tortuous course from the capsule to the next portion (loop of Henle). Its walls are of cuboidal epithelium, the cells being pyramidal in shape; their surfaces on the inside of the tubule show a brush border, a finely striated zone lining the lumen.

The *loop of Henle* consists of two straight limbs running parallel to each other. The *descending limb* is very narrow (14 to 22 microns in diameter); the *ascending limb* is somewhat thicker (about 33 microns). Most of the loop of Henle lies in the medullary portion of the kidney. The cells comprising the descending limb are of the squamous epithelium type; those in the ascending limb are cuboidal.

The *distal convoluted portion* is short (4 to 5 mm.) and much convoluted. It leads to a short, arched connecting portion which empties into a straight collecting duct.

COLLECTING (OR EXCRETORY) DUCT. The nephrons connect with straight excretory ducts in the cortical region. Each duct passes centrally through the outer zone of the medulla to the inner zone, where several may join together into a single large collecting tubule, the *papillary duct* (*duct of Bellini*). The papillary ducts open on the tip of a renal papilla and empty their contents into a minor calyx of the renal pelvis. The cells of the smaller ducts are cuboidal; those of the larger ducts are columnar.

BLOOD AND LYMPHATIC SUPPLY OF THE KIDNEY. Blood enters the kidney at the hilus through the *renal artery*, which divides into a number of branches which, in turn, lead to the *interlobar arteries*. These last-named extend radially between the pyramids and connect with *arcuate arteries*, which run parallel to the surface in the boundary zone between the cortex and the medulla. From the arcuate arteries, *interlobular arteries* lead peripherally into the cortex. These give rise to the *afferent arteries* leading to the glomeruli.

Near each glomerulus the smooth muscle cells of the afferent artery become epithelioid in appearance and form a collar-like structure called the *juxtaglomerular apparatus*. The function of this apparatus, which somewhat resembles the carotid and aortic bodies in structure, is not known. It has been suggested that it secretes a hypertensive substance.

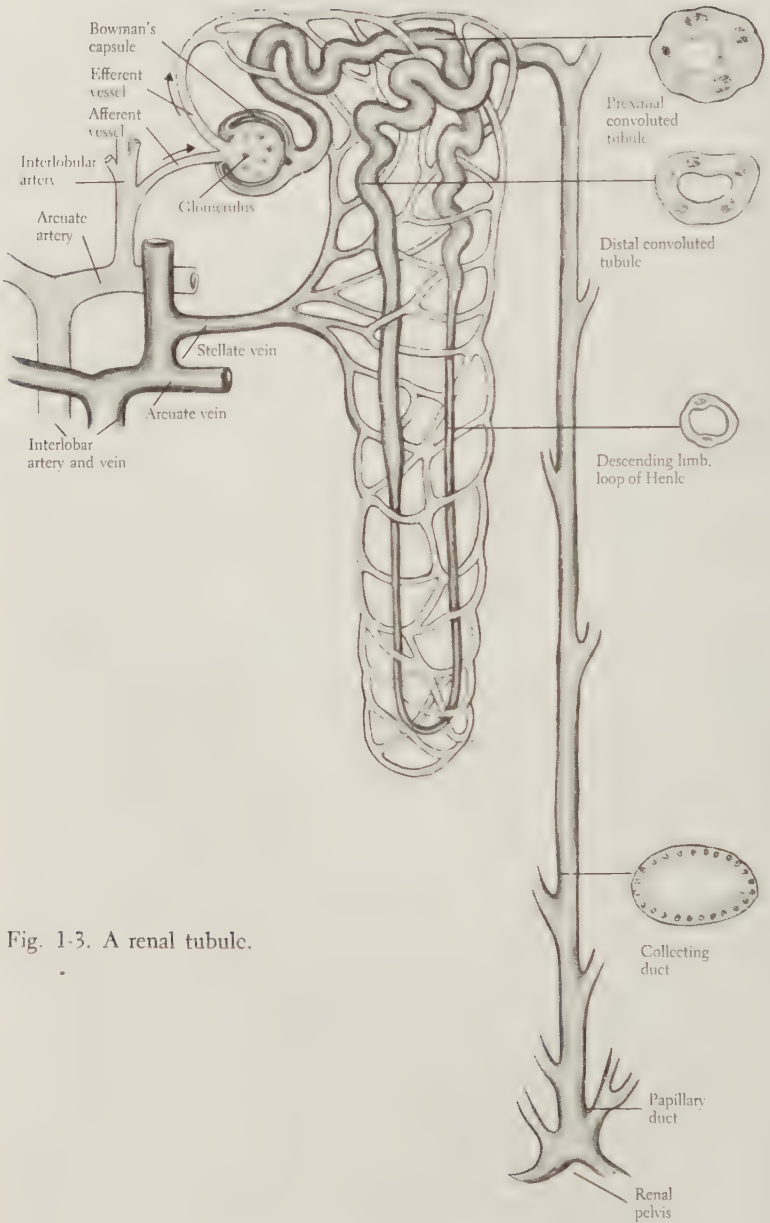


Fig. 1-3. A renal tubule.

Within the capsule the afferent arteriole divides into four or five branches which subdivide further into looped capillaries. These capillaries form a lobate structure, the *glomerulus*. Anastomoses are infrequent. The capillaries join and leave the glomerulus as the efferent arteriole, which continues a short distance, then breaks up into a *second capillary network*. This is a plexus surrounding the convoluted portions of the tubules in the cortex and the loop of Henle in the medulla. Branches of the efferent vessels and straight arteries, branching from the arcuate artery, supply blood to the medullary rays, the medulla, and the pyramids. Those supplying the pyramids are the *arteriolae rectae*.

Capillaries of the cortex converge to form the *stellate veins*, which lead to *interlobular veins*, and these, in turn, lead to the *arcuate veins*, which parallel the arcuate arteries. Blood from the medulla is collected in the *straight veins*, which enter the arcuate veins. Finally, the arcuate veins lead to *interlobular veins* of the medulla, passing between the pyramids and uniting to form the *renal vein*, which emerges from the kidney at the hilus.

The kidney is also well supplied with *lymphatic vessels*. Both the capsule and the glandular tissue contain dense networks of lymphatic capillaries, which drain into efferent vessels. These vessels leave at the hilus and enter the lymph nodes lying along the aorta.

NERVE SUPPLY OF THE KIDNEY. Each kidney is innervated by sympathetic nerve fibers from the *celiac plexus*. Both myelinated and non-myelinated fibers accompany blood vessels into the kidney substance, where they end principally in the walls of the blood vessels. Both sensory and motor nerve endings are present. The exact relationship between the nerve fibers and the tubules is still in question. Some investigators have described plexuses around the tubules; some have claimed that the nerve fibers penetrate and end in the epithelium of the tubules.

Structure of the Excretory Passages. The urinary excretory passages comprise the ureters, the urinary bladder, and the urethra.

URETERS: The renal calyces and the renal pelvis, which lie within the sinus of the kidney, have already been described. They constitute the expanded end of the ureter, a tube which connects the kidney with the urinary bladder. Each ureter consists of an abdominal portion and a pelvic portion. The *abdominal portion* descends behind the parietal peritoneum to the brim of the pelvis, which it crosses. The *pelvic portion* curves laterally, downward, forward, and inward, to enter the bladder at the lateral corner of the trigone. The ureter averages 27 cm. in length and 4 to 5 mm. in diameter.

In cross section, the ureter is seen to possess the following layers:

A *mucous coat*, a layer of transitional epithelium with an under-

lying lamina propria of dense connective tissue. The epithelium lacks a basement membrane. The mucous coat is usually thrown into several longitudinal folds.

A *muscular coat*, consisting of an inner longitudinal and an outer circular layer. The layers are not easily distinguishable because fibers from one layer may penetrate the other.

A *fibrous coat*, consisting of fibrous connective tissue with bundles of collagenous fibers interspersed with elastic fibers.

URINARY BLADDER. The urinary bladder is an ovoid muscular sac lying in the anterior portion of the pelvic cavity directly behind the symphysis pubis. In the male, it lies anterior to the rectum; in the female, it lies anterior to the uterus and the vagina. It receives urine from the ureters, which pass through the bladder wall obliquely on its lower posterior surface. The urine is stored temporarily and discharged at intervals through the urethra. The triangular area lying between the opening of the urethra and the openings of the two ureters is the *trigone*.

Owing to the oblique course by which the ureters enter the bladder and the presence of a fold of mucous membrane at each ureteral opening, which acts as a valve, urine is prevented from re-entering the ureters as the bladder fills.

The layers of the bladder wall are virtually the same as those of the ureter, the muscular coat being especially well developed. This coat consists of three layers of smooth muscle cells somewhat indistinctly separated from each other. The outer layer, designated the *detrusor urinae*, consists of longitudinal fibers. The fibers of the middle layer run circularly; those of the inner layer, which are especially well developed in the region of the trigone, run longitudinally. About the internal opening of the urethra, the smooth muscle forms a dense mass, the *internal sphincter* of the bladder. On the free superior surface the fibrous coat has a layer of peritoneum.

The *blood supply* of the urinary bladder comes from the *hypogastric (internal iliac) arteries*. Veins form several plexuses, which empty into the *internal iliac vein*. The bladder is also well supplied with *lymphatics*.

Nerves from both divisions of the autonomic nervous system innervate the urinary bladder. Details of the nerve supply are given in the section on Micturition (page 13).

URETHRA. The urethra is the duct that conveys urine from the bladder to outside the body. In the male, it also carries semen and thus serves as a common excretory and reproductive duct. In the female, its function is exclusively excretory.

The *female urethra* is relatively short, measuring 3 to 4 cm. in length. It passes inferiorly along the anterior surface of the vagina, to

which it is firmly attached, and opens at the *urethral orifice*, which lies in the vestibule between the vaginal orifice and the glans clitoridis. The mucous membrane is lined with stratified squamous epithelium except near the bladder, where it is of the transitional type. It is thrown into longitudinal folds, a prominent fold on the posterior surface forming the *urethral crest*. Urethral glands, the *glands of Littré*, open into lacunae located between these folds. The ducts of the largest urethral glands, the *para-urethral glands* (*glands of Skene*) open just within the urethral orifice. The lamina propria, also called submucosa, is rich in elastic fibers and has a cavernous character. The muscular layer is thick, with the inner fibers running longitudinally and the outer ones circularly. A fibrous membrane forms the outermost layer. Just within the orifice is a sphincter of circular smooth muscle fibers (the *urovesical sphincter*); at the orifice is a sphincter of striated fibers (the *urogenital sphincter*).

The *male urethra* extends from the bladder to the tip of the penis. It averages 20 to 25 cm. in length and consists of *prostatic*, *membranous*, and *cavernous portions*.

The prostatic portion of the male urethra averages 2 to 3 cm. in length and is surrounded by the prostate gland whose ducts open into its floor and lateral surfaces. Its walls possess numerous longitudinal folds, a prominent one on its posterior surface being the *urethral crest*. This crest dilates in the midregion to form the *colliculus seminalis*, which bears on its sides the two small openings of the *ejaculatory ducts*. The prostatic portion passes through the pelvic floor and continues as the membranous portion.

The membranous portion averages 1 cm. in length; its diameter is considerably less than that of the other two portions. Its walls contain the fibers of a sphincter muscle, the *sphincter urethrae membranaceae*.

The cavernous portion has two parts: a short proximal portion, which is fixed in position, and a distal portion, which lies in the penis and is mobile. On entering the penis, the urethra dilates to form the bulb of the urethra, which contains the openings of the ducts of the bulbo-urethral glands. At the glans penis the cavernous portion dilates as the *fossa navicularis urethrae*, which opens to the outside through the *urethral orifice* at the tip of the penis.

The cavernous urethra is surrounded by erectile tissue, the *corpus cavernosum urethrae*. The mucous membrane in the prostatic portion is lined with transitional epithelium like that of the bladder. In the membranous and cavernous portions, the epithelium is stratified columnar or pseudostratified up to the fossa navicularis, where it changes to stratified squamous. In the cavernous portion, the mucous membrane shows many outpocketings called *lacunae urethrales* (*lacunae of Morgagni*). These receive the openings of numerous small glands, the

glands of Littré. A definite submucosa is lacking, the mucosa being surrounded by a layer of loose connective tissue containing scattered bundles of smooth muscle cells and numerous veins, the whole being enclosed in a thin layer of connective tissue, the *tunica albuginea*.

PHYSIOLOGY OF THE URINARY SYSTEM

Inasmuch as the urinary system is concerned exclusively with the collection, temporary storage, and excretion of urine, it is essential that the nature of that substance be established.

Constituents of Urine. Urine consists of water (95 per cent) and solids (5 per cent). The solids, which amount to 40 to 50 gm. per liter of urine, consist of both organic and inorganic substances. The principal constituents of each of these groups and the average grams per liter in normal urine are shown in the following table:

| Organic Constituents | gm./L. | Inorganic Constituents | gm. L. |
|----------------------|--------|------------------------|--------|
| Urea | 23.0 | Sodium chloride | 9.0 |
| Hippuric acid | 0.6 | Potassium chloride | 2.5 |
| Uric acid | 0.6 | Sulfuric acid | 1.8 |
| Creatinine | 1.5 | Phosphoric acid | 1.8 |
| Other substances | 2.0 | Ammonia | 0.6 |
| | | Calcium | 0.2 |
| | | Magnesium | 0.2 |

Besides those named above, other substances, depending on the diet and general health of the individual, may be present in varying amounts, usually in minute quantities or merely as traces: carbohydrates, pigments (urochrome, urobilin), fatty acids (aceto-acetic, beta-hydroxybutyric), carbonates, bicarbonates, carbonic acid, mucin and mucin-like substances, enzymes, and hormones.

Sources of Urinary Constituents. The sources of the principal urinary constituents are:

UREA. Urea, $\text{CO}(\text{NH}_2)_2$, comprises 60 to 90 per cent of all nitrogenous material in urine. It is derived principally from the catabolism of amino acids. In the oxidative deamination of amino acids in the liver and other tissues, ammonia is formed, which combines with carbon dioxide to form urea. The amount of urea in the blood is referred to as *blood urea nitrogen* (b.u.n.); it averages 12 to 20 mg. per 100 cc. of blood. The b.u.n. rises in uremia.

AMMONIA. Ammonia, NH_3 , occurs in urine in the form of ammonium salts, principally chlorides and urates. It originates from deamination of amino acids but may also be formed in the kidney itself from glutamine. Ammonia functions to neutralize body acids. In acidosis the production of ammonium salts by the kidney helps to prevent excessive loss of sodium carbonate from the blood.

URIC ACID. Uric acid is an end product of purine metabolism in

man. It is formed in part from purines ingested in food (exogenous) and from those formed in the body (endogenous). The latter are derived principally from nucleoproteins. Uric acid is markedly insoluble in water, although its salts are more readily soluble. Owing to this insolubility, it tends to crystallize and is a common component of kidney stones. When the uric acid concentration of the blood rises, uric acid and its salts tend to be deposited in and around the joints and in cartilages. Such deposits, called *tophi*, occur in tophaceous *gout*.

CREATININE. A normal, alkaline constituent of the blood, creatinine ($C_4H_7ON_3$) is thought to be derived from creatine, a nitrogenous substance present in muscle tissue. Its daily output in urine is remarkably constant, averaging 0.02 mg. per Kg. of body weight.

MINERALS. The amounts of sodium and potassium in urine closely parallel the amounts ingested in foods. Calcium and magnesium are eliminated principally via the large intestine; consequently, they do not appear in significant quantities in the urine.

SALTS. *Chlorides* are derived principally from excess salts in the diet. The concentration of chlorides in the blood remains constant—when the salt intake is excessive, the salt content of the urine is high; on a salt-free diet, the urinary content is extremely small. In vomiting, when a considerable amount of chlorides may be lost, the urinary chloride is reduced. *Sulfates* are derived principally from the amino acids of dietary protein. *Phosphates* occur in the urine as sodium compounds (monosodium and disodium phosphate); the former of these is acid, the latter alkaline. Phosphates may also occur in the form of potassium, calcium, and magnesium compounds. Monosodium and disodium phosphates are present in the blood in the ratio of 1:4; they serve as buffers, helping to maintain the normal alkalinity of the blood. In urine their ratio is reversed and is approximately 9:1. By this mechanism, the body's fixed base, chiefly sodium, is conserved.

HORMONES. Several hormones, especially those secreted by the reproductive organs and the hypophysis, are excreted in urine. Tests used in the diagnosis of pregnancy are based on the presence of chorionic gonadotrophins secreted by the placenta of a pregnant woman.

Characteristics of Urine. The following are characteristics of urine under normal and abnormal conditions:

COLOR. Urine normally is amber in color, owing to the presence of a pigment, *urochrome*, the origin of which is unknown. Drugs, pathologic conditions, or the ingestion of certain foods may alter the color.

TRANSPARENCY. Normal urine is usually clear and transparent. On standing, however, it tends to become cloudy and a sediment may appear, owing to bacterial action which results in the production of phosphates of calcium and magnesium. These substances are insoluble in alkaline urine; consequently, they precipitate out. Bacterial infec-

tions of the urogenital tract may produce similar conditions and result in a cloudy urine.

REACTION. Urine is usually *acid*, with a pH around 6.0, the acidity being due chiefly to the presence of sodium acid phosphate, NaH_2PO_4 . The reaction varies considerably with the nature of the diet; vegetable foods and fruits tend to reduce the acidity and to produce an alkaline urine. The acidity of the urine increases in starvation and in certain diseases such as diabetes mellitus.

SPECIFIC GRAVITY. The specific gravity of urine is variable. In health, it is from 1.015 to 1.025. Excessive water intake results in a large volume of urine of low specific gravity. Low water intake or excessive loss of water through other avenues (lungs, skin, and intestines) decreases the volume of urine formed, with a resultant increase in specific gravity. In pathologic conditions, the kidney may be unable to vary the specific gravity according to the needs of the body; consequently, it may be high or low, or it may tend to become "fixed."

VOLUME. The average amount of urine daily excreted ranges from 1000 to 1800 cc. (average about 1500 cc.). Many factors tend to alter the amount, among them: *diet* (a high protein diet increases urinary output because urea, sulfates, and phosphates tend to act as diuretics); *water intake*; *loss of water* through channels other than the urinary system (in summer, urinary output is decreased owing to increased sweating); and *degree of body activity* (urine flow is decreased during sleep, increasing markedly two to three hours after arising, and strenuous muscular activity results in reduced urine formation).

THE FORMATION OF URINE

The substances which the kidney eliminates in the form of urine are, with one or two exceptions, those substances which normally are present in the blood. Accordingly, the kidneys act to maintain the constancy of the blood by removing substances which are present in excess quantity. This is accomplished by the processes of *filtration* and *reabsorption*, performed by the nephrons.

Filtration. The glomerulus and glomerular epithelium act as a filter. As the blood passes through the glomerulus, water and dissolved substances pass through the capillary walls and the epithelium into the capsule, to form the *glomerular filtrate*. Blood cells and colloidal substances such as proteins, because they consist of particles too large to pass through the epithelium, are retained in the capillaries. Blood pressure (hydrostatic pressure) provides the force for filtration. The reduced size of the efferent vessel of the glomerulus assists in building up filtration pressure.

GLOMERULAR FILTRATE. The glomerular filtrate is similar in composition to the blood plasma, excepting that it is protein-free. Water,

salts, and sugar are present in approximately the same concentrations as in the blood. This fluid passes along the tubule and enters the renal pelvis as *urine*. Examination of this urine shows that it contains *less* water, *more* urea, and *no* sugar. The concentrations of salts, too, are altered, some being increased, some decreased.

There is evidence that the cells of the tubule may add certain substances (urea, uric acid, and others) to the filtrate. These substances may be derived from the blood (tubular excretion), or they may be produced by the cells themselves (tubular secretion).

FILTRATION CAPACITY OF THE KIDNEYS. There are approximately two million glomeruli in the two human kidneys, with a filtration surface of about 5000 sq. mm. per gm. of kidney. Blood flow through the kidneys is large, averaging 1000 to 1200 cc. per minute (about one-fourth of the cardiac output). Nearly 16 liters of glomerular filtrate are formed each 24 hours. Through reabsorption this is concentrated and is reduced to about 1 to 2 liters of urine.

Reabsorption. The foregoing facts indicate that as the glomerular filtrate passes along the tubule, some of the substances are reabsorbed into the blood in the capillaries surrounding the tubule. Because these substances are reabsorbed in varying amounts, the process is referred to as *selective absorption*, and the substances are regarded as either high-threshold, low-threshold, or non-threshold substances.

HIGH-THRESHOLD SUBSTANCES. Substances that are entirely or almost entirely reabsorbed along with water are known as high-threshold substances. These include glucose, chlorides of sodium, potassium, calcium, and magnesium, all of which are important constituents of the body fluids and which are excreted only when their concentrations in the blood are greater than normal. They are present in normal urine only in limited quantities.

LOW-THRESHOLD SUBSTANCES. These are substances which are reabsorbed in limited quantities; consequently, they appear in the urine in considerable amounts. Examples are urea, uric acid, and phosphates.

NON-THRESHOLD SUBSTANCES. These substances are excreted in their entirety. Examples are creatinine and sulfates.

Factors Affecting the Formation of Urine. Although the formation of urine is principally a passive process, the amount of urine that is produced varies with and is dependent on nervous, chemical, and physical factors. The volume *increases* as a result of an increased rate of filtration, a reduced rate of absorption, or a combination of these. The volume of urine *decreases* under the reverse of these conditions.

FACTORS AFFECTING THE FILTRATION RATE. The primary factors which influence the filtration rate are:

1. *Variations in the extent and nature of the glomerular filtering surface.* The number of glomeruli functioning at any one time is

variable, depending on nervous and chemical influences. Furthermore, the number of functional capillary loops within a glomerulus may also vary.

2. *Pressure within the glomeruli.* This is dependent on systemic blood pressure or on changes within the kidney itself; these factors bring about an increased supply of blood to the kidney or an increased glomerular flow.

3. *Osmotic pressure relationships.* Proteins in the blood exert an osmotic pressure which acts to draw water from the capsule back into the glomerular capillaries. *Filtration pressure* is the difference between the blood pressure forcing fluids out of the glomerular capillaries and the osmotic pressure drawing the water back in. *Blood pressure* in the kidney capillaries averages about 70 mm. Hg; osmotic pressure of the plasma proteins averages about 30 mm. Hg. Filtration pressure consequently averages about 40 mm. Hg (that is, 70 mm. minus 30 mm.). The fluids in Bowman's capsule, however, exert a back pressure of about 5 mm.; consequently, the *effective filtration pressure* is about 35 mm.

FACTORS AFFECTING THE REABSORPTION RATE. The primary factors influencing the rate of reabsorption are:

1. *Rate of flow along a tubule.* When the flow is rapid, there is less opportunity for reabsorption.

2. *Osmotic pressure of the filtrate.* Reabsorption requires the expenditure of energy by the cells of the tubules. As reabsorption proceeds, the filtrate becomes more concentrated and the osmotic pressure rises. Reabsorption of water ceases when the osmotic pressure exceeds the power of cells to take out water.

3. *Unknown factors.* The selective action of the tubular epithelium falls within this category.

Control of Urinary Secretion. Secretion of urine is accomplished under nervous and chemical control.

NERVOUS CONTROL OF URINARY SECRETION. This is accomplished *directly*, through the action of nerve impulses on the blood vessels leading to the kidney and on those within the kidney leading to the glomeruli, and *indirectly*, through the effects of nerve impulses on certain endocrine glands.

CHEMICAL CONTROL OF URINARY SECRETION. This is accomplished through the effects of chemical substances in the blood. Hormones play an important role. The posterior lobe of the pituitary stores an antidiuretic factor called *vasopressin*, which is thought to exert its effect by influencing the reabsorption of water and salts by the cells of the tubule. In the absence or reduced secretion of this hormone, reabsorption of water is decreased and the reabsorption of sodium chloride is increased. The volume of urine is greatly increased, and the

urine is very dilute (a condition characteristic of diabetes insipidus). Adrenal cortical hormones also affect the excretion of water and salts. In their absence, water and sodium are excreted in excessive amounts, and potassium is retained. Adrenocortical insufficiency results in pronounced changes in the salt and water content of the body fluids.

MICTURITION

As urine is secreted by the kidneys, it enters the ureters, through which it is forced into the bladder by the peristaltic contraction of the smooth muscles in the ureteral walls. While the urine is slowly accumulating, the *detrusor* muscle in the bladder wall relaxes and adjusts its tone to the increased volume. When about 300 cc. of urine has collected, sensory receptors in the bladder wall are stimulated, and the desire to urinate is experienced. Release of voluntary control permits efferent impulses to be discharged which bring about relaxation of the sphincter muscles and contraction of the bladder wall. As a consequence, urine is discharged through the urethra with considerable force. This is known as urination or *micturition*.

Innervation of the Urinary Bladder and the Urethra. The urinary bladder and the urethra are innervated by efferent and afferent fibers from the sympathetic and parasympathetic divisions of the autonomic nervous system.

EFFERENT FIBERS INVOLVED IN MICTURITION. Sympathetic efferent fibers originate in the lumbar region of the spinal cord and pass through the inferior mesenteric plexus and superior hypogastric plexus via the presacral nerves to the inferior hypogastric plexus. Postganglionic fibers originating from this ganglion pass to the bladder and the internal sphincter. These fibers carry *inhibitory* impulses to the detrusor muscle and *motor* impulses to the trigone, the internal sphincter, and smooth muscle in the proximal portion of the urethra. Parasympathetic fibers originate in the sacral region of the spinal cord. They pass through the pelvic nerves and synapse with neurons in the bladder wall and in the region of the internal sphincter muscle. These fibers carry *motor* impulses to the detrusor muscle and *inhibitory* impulses to the internal sphincter. These two sets of nerves are antagonistic in their actions, the former operating to fill the bladder and retain urine, the latter to evacuate the bladder. *Somatic efferent* or motor fibers from the spinal cord pass through the *pudendal* nerves to the striated muscle of the external sphincter.

AFFERENT FIBERS INVOLVED IN MICTURITION. Afferent or sensory fibers pass from the bladder through the pelvic and hypogastric nerves to the spinal cord, carrying impulses set up by distention of the bladder wall and impulses of pain, touch, and temperature. Afferent fibers from the urethra pass through the pudendal nerves to

the spinal cord, carrying impulses originating from distention of the urethra.

Steps in Micturition. All processes involved in emptying the bladder are reflex in nature, but they are susceptible to voluntary control and, within limits, can be inhibited or initiated at will. The steps in the process are in general as follows:

1. When the volume of urine in the bladder reaches about 300 cc., the resulting distention of the bladder wall initiates afferent impulses which, on reaching the brain, give the sensation of bladder fullness and the desire to urinate. If voluntary restraint is released, the succeeding steps occur.

2. The smooth muscle in the proximal portion of the urethra is relaxed. Afferent and efferent pathways of this reflex are over the pelvic nerves, with the reflex center located in the spinal cord.

3. The external sphincter is relaxed. The afferent pathway for this is through the pelvic nerves; the efferent pathway is through the pudendal nerves. The reflex center is in the spinal cord.

4. The detrusor muscle of the bladder wall contracts, and this is accompanied by relaxation of the internal sphincter. For this reflex, both afferent and efferent pathways are in the pelvic nerves, with the reflex center in the pons.

(As the urine passes along the urethra, the following two additional reflexes are initiated.)

5. There is continued contraction of the detrusor muscle. The afferent pathway is through the pudendal nerves, and the efferent pathway is through the pelvic nerves, with the reflex center in the medulla. This reflex brings about a continuation of the contraction of the bladder until all the urine has been expelled.

6. There is continued relaxation of the external sphincter. The afferent and efferent pathways are in the pudendal nerves, with the reflex center in the sacral region of the cord.

The expulsion of urine also involves activity by the muscles of the abdominal wall and the perineum. Contraction of the abdominal wall increases intra-abdominal pressure and usually starts the process of micturition. At the same time, muscles of the perineum are relaxed. Contraction of the bulbocavernous muscle brings about expulsion of the urine that remains in the urethra.

In *infants*, urination is entirely under reflex control; voluntary control is acquired through training. Voluntary control in adults is sometimes lost as a result of spinal cord lesions or emotional disturbances.

WATER BALANCE

Water is the most important, as well as the most voluminous, compound in the body. Because the kidney plays a primary role in the

maintenance of water balance in the body, this topic is included here, under the urinary system.

Water comprises about 65 to 70 per cent of body weight. Most of this (about 65 per cent of the water) is *intracellular*, constituting an integral part of the protoplasm of cells. The remainder is *extracellular*, being found in the tissue fluid between the cells or in the body fluids (blood, lymph, spinal fluid, synovial fluid) and the secretions of the glands. The distribution of water in tissue varies with the types of tissue; in the following table the percentages of water in some representative tissues are given:

| | Per Cent |
|------------------------------|----------|
| Fatty tissues | 6-10 |
| Bone (extremities and skull) | 14-22 |
| Bone (vertebrae and ribs) | 16-44 |
| Tendon | 56-58 |
| Brain (white matter) | 68-70 |
| Muscle tissue | 75-78 |
| Thyroid gland | 77-81 |
| Brain (gray matter) | 82-85 |

Water balance is that condition in which water intake is in balance with water output. The normal composition of the body fluids depends on this balance.

Water Intake. The total intake of water varies with individuals, but the average is about 2500 cc. per day. Of this quantity, about 2200 cc. is ingested *per ora* (1200 cc. in liquids and 1000 cc. as water in solid foods). The remainder, about 300 cc., called "metabolic water," is derived from the oxidation of foods in tissue cells. Water intake is influenced by the amount of muscular activity, body and environmental temperatures, and the nature of the diet.

Water Output. The avenues by which water is lost and the average amount of water lost per day, at average temperature and humidity, are as follows:

| | |
|---------------------|----------|
| Through the skin | 500 cc. |
| Through the lungs | 350 cc. |
| Through the kidneys | 1500 cc. |
| Through the feces | 150 cc. |

WATER LOST THROUGH THE SKIN. Naturally, these amounts vary in response to changing conditions. When the body temperature rises, as from muscular exercise, fever, or increased environmental temperature, the amount of water lost through the skin by perspiration is greatly increased. Sweating serves as a means for dissipating excess heat. With the loss of water, there is also a considerable loss of salts, principally sodium chloride. For normal body functioning, both the

water and the sodium chloride must be replaced (leading to the desirability of increased salt intake in hot environments).

WATER LOST THROUGH THE LUNGS. The amount of water lost through the lungs varies with the nature of the air inspired and the rate and depth of breathing. If the inspired air is dry, more water is lost than when the inspired air is laden with moisture. Rapid breathing or breathing through the mouth increases water loss.

WATER LOST THROUGH THE KIDNEYS. When a great deal of water is lost through the skin, the amount lost through the kidneys is noticeably reduced. The kidneys are, however, the *primary* organs for the regulation of water balance. When there is an excess of water in the body, the excess is eliminated through the formation and excretion of urine. When the water supply is low, the quantity of water thus eliminated is reduced, and the salts and waste products become concentrated.

WATER LOST THROUGH THE FECES. This is fairly constant from day to day. It is increased by diarrhea, decreased by constipation.

OTHER AVENUES. Small amounts of water are also lost through the sputum, tears, and (in a lactating mother) milk.

Regulation of Water Balance. A number of mechanisms operate to maintain a balance between water intake and water output and thus achieve constancy in the concentration of the body fluids. Water intake is largely regulated by the sensation of *thirst*. Thirst is induced by a reduction in body water and may be due to (1) reduced intake, (2) excessive loss of water through sweating, diarrhea, vomiting, or polyuria, (3) loss of blood, or (4) excessive salt intake or intravenous injections of hypertonic solutions. The sensation of thirst itself comes about from the drying of the mucosa of the mouth and pharynx (owing to reduced secretion of saliva) or from general dehydration of the tissues. The sensation of thirst is projected to the mouth and pharynx, and moistening of these parts relieves thirst for a short time. No special receptors for thirst have been identified, nor has any specific thirst center been located in the brain.

Hormones play an important role in water balance. When water loss is excessive, the osmolarity of the blood is altered. This stimulates *osmoreceptors* in the hypothalamus which in turn stimulate neurosecretory cells of the hypothalamus to release *vasopressin*, the antidiuretic hormone. Urine output is reduced and water conserved. Adrenal cortical hormones, especially *aldosterone*, also play a role by increasing sodium and chloride reabsorption in the kidney.

Dehydration. Under normal conditions, a considerable amount of water is stored in the body, principally in the loose connective tissue. When water intake is inadequate, the body draws on these reserves. If the imbalance continues for any appreciable length of time, the

tissues begin to lose water, and dehydration sets in. Loss of water up to 5 to 10 per cent of body weight constitutes serious dehydration; a loss of 20 per cent is usually fatal. In dehydration, the blood becomes more concentrated (*anhydremia*) and reduced in volume (*oligemia*). Under average conditions, a person may live for 12 to 20 days without water, but if also exposed to heat may survive only two or three days.

Some *effects* of dehydration are: excessive thirst, loss of weight, change in acid-base balance of body fluids, increase in body temperature, and change in texture of the skin. Some *causes* are: reduced fluid intake, vomiting, diarrhea, excessive perspiration, excessive loss of blood, acidosis, and salt deficiency.

Water Intoxication. Under normal conditions, when large quantities of water are ingested the excess is eliminated by the kidneys. In cases of kidney disorder, however, when urinary secretion is reduced, the tissues may become saturated with water, giving rise to *water intoxication*. The symptoms manifested in this condition are: headache, dizziness, reduced body temperature, vomiting, convulsions, and coma. Occasionally, it is fatal.

It is a curious fact that water intoxication prevails in the early stages of starvation. It has also been observed that in the course of a restricted dietary regimen the body may lose little weight during the first week or two; this is explained by the replacement with water from the oxidation of adipose tissue. But if the reduced diet is continued, there will eventually occur a sudden loss of weight owing to the rapid loss of water through the kidneys.

Edema. The excessive accumulation of fluid in the tissues, known as edema, is due to a lack of balance between the rate of formation of tissue fluid and lymph and the rate at which lymph re-enters the blood stream. Edema may result from venous obstruction, cardiac or renal disease, faulty metabolism, lymphatic obstruction, or inflammatory conditions.

TESTS OF URINE AND OF URINARY FUNCTION

Two of the most commonly employed methods of investigating the urine and urinary function of an individual to diagnose or uncover abnormal conditions are *urine analysis* and the *renal clearance test*.

Urine Analysis. Popularly referred to as "urinalysis," the examination of urine is extremely important in that many pathologic conditions or metabolic disturbances can be detected by changes that occur in the nature of the urine. Certain substances may be present which are not normal constituents of urine, or the proportions of the normal constituents may be altered. Some of the substances not normally present are: glucose, acetone, albumin, blood, and pus. The following conditions reflect such abnormal constituents.

GLYCOSURIA. When glucose (sugar) is found in the urine, it may be a sign of (1) alimentary glycosuria due to excessive intake of sugar; (2) emotional glycosuria, probably the result of excessive activity of the adrenal gland which has caused the breakdown of glycogen and liberation of sugar from the liver; (3) hypoinsulinism from failure of the islets of Langerhans to produce insulin, the primary factor in diabetes mellitus; (4) glycosuria of pregnancy or lactation, owing to the presence of lactose; (5) glycosuria due to overactivity of the posterior lobe of the hypophysis; (6) low renal threshold for glucose.

ACETONURIA. Acetone, a product of incomplete combustion of fats, makes its appearance in urine when excessive amounts of fats are consumed or when inadequate amounts of carbohydrates are oxidized (as in diabetes mellitus). Acetone is also produced in starvation, when body fat is oxidized.

ALBUMINURIA. "Proteinuria" would be a more inclusive term because it would designate more accurately what is meant—the presence in urine of any of the plasma proteins (serum albumin, serum globulin, serum fibrinogen). But the albumin is the most common of the proteins to be found in urine, and its presence indicates that the glomerular epithelium is not serving as an effective filter. It is usually regarded as evidence of kidney disease, although it can occur in the absence of renal pathology. Some types of albuminuria are:

Cyclic or adolescent albuminuria. In young individuals small amounts of albumin may appear at stated times of the day.

Postural or orthostatic albuminuria. This form of albuminuria appears only when the subject is standing or sitting. It disappears when a reclining position is assumed. It is seen especially in persons afflicted with lordosis and is probably due to mechanical factors which impede circulation in the kidney.

Functional or benign albuminuria. This is a mild albuminuria which may result from excessive intake of proteins, strenuous muscular activity, cold baths, pregnancy, or other conditions. It has no pathologic significance.

HEMATURIA. The appearance of blood in the urine may be the result of infections involving the kidney or the urinary tract, mechanical injury to the kidney, or an abnormal growth within the urinary system.

PYURIA. Pus in urine is taken as evidence of infection involving the kidney or the urinary tract.

CASTS. Casts, usually molded in the form of tubules, are sometimes revealed by microscopic examination of urine. Among the types found are: *hyaline casts*, consisting of coagulated protein material; *granular casts*, consisting of blood, epithelial cells, and albumin; and *fatty or waxy casts*. Casts in urine are often signs of renal disease or injury, though they may be found in the urine of healthy individuals.

Renal Clearance Test. By the intravenous injection of *inulin* (which is not utilized by the body) and determination of the degree and rate of its excretion by the kidney, the *rate of glomerular filtration* can be estimated. This test is also known as the *inulin clearance test*. It is helpful in determining the effectiveness of kidney function.

DISORDERS OF THE URINARY SYSTEM

The urinary system is responsive to many bodily disturbances. The more common of the functional disorders and abnormal distribution of substances associated with this system are described in the following paragraphs. They are indications of a wide range of pathologic conditions.

Anuria. This is the cessation of production of urine by the kidneys. Some causes are: acute nephritis; obstruction of one or both ureters; blockage of kidney tubules or of blood vessels leading to the glomeruli; effects of poisons, such as ether, phosphorus, lead, and turpentine; and the aftereffects of certain diseases (e.g., cholera and typhoid fever).

Dysuria. Difficult or painful micturition is known as dysuria.

Enuresis. In infants, the process of micturition is involuntary. When involuntary discharge of urine occurs after the age of about two or three years, it is regarded as abnormal. It is called *diurnal enuresis* if occurring during the day, *nocturnal enuresis* (or *nocturia*) if occurring at night (usually during sleep). Enuresis may be due to faulty toilet training, psychogenic factors, or (less often) pathologic conditions.

Incontinence. This condition, the inability to retain urine, may be due to structural factors (such as poorly developed sphincter muscles), pathologic conditions (lesions involving the reflex centers controlling these functions), or psychogenic factors.

Oliguria. In this condition the amount of urine formed is markedly decreased.

Retention. This condition, the inability to expel urine from the bladder, may be due to: loss of muscle tone in the bladder (as from anemia, advanced age, or wasting disease); obstruction of, or stricture in, the urethra; lesions involving the nervous pathways to and from the bladder or the reflex centers of the brain and the spinal cord; and psychogenic factors.

Uremia. This is a toxic condition in which nitrogenous substances accumulate in the blood. It is a sequela of anuria.

PATHOLOGIC CONDITIONS

Cystitis. Inflammation of the bladder.

Kidney Stone. Also called renal calculus, an abnormal concretion usually containing uric acid, calcium oxalate, or phosphates. Small stones may enter and pass through the ureter; this experience is usually accompanied by intense pain called *renal colic*. Stones in the kidney, ureter, bladder, or urethra interfere with the passage of urine and may give rise to *hydronephrosis* (excessive accumulation of urine in the pelvis), distention of the bladder, and atrophy of the kidney.

Movable Kidney (Nephroptosis). The kidney is capable of moving to a limited extent in response to respiratory movements and changes in body po-

sition. When the movements are greater than normal, the condition is referred to as *movable kidney*. In extreme cases, it is called *wandering* or *floating* kidney. It occurs more frequently on the right side than on the left, more frequently in women than in men.

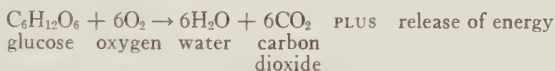
Nephritis (Bright's disease). Inflammation of the kidney. It may involve the glomeruli, the tubules, the parenchyma, or the entire kidney. Nephritis may be acute or chronic. It is usually accompanied by albuminuria and edema.

Pyelitis. Inflammation of the renal pelvis and its calyces.

Stricture. Abnormal narrowing of the ureter or urethra, which may result from an inflammatory condition or a spasm of the muscles in their walls.

2: THE RESPIRATORY SYSTEM

The respiratory system comprises those organs which are concerned with the exchange of gases between the organism and its environment, specifically the intake of oxygen and the discharge of carbon dioxide. The exchange of gases between the blood and the air taken into the lungs is *external respiration*; the exchange of gases between the circulatory fluids (blood, lymph, tissue fluid) and the cells is *internal respiration*. The significance of respiration lies in the fact that life processes depend primarily on the release of energy from food substances, and the basic reaction for this is:



This is physiologic oxidation or destructive metabolism (*catabolism*). The maintenance of life demands a continual supply of oxygen and continual removal of carbon dioxide. Because the tissues are unable to store any appreciable quantity of oxygen, a cessation of respiratory activities or interference with the distribution of oxygen to the organs and tissues results in malfunctioning or deterioration of the organs and tissues and possibly death of the organism.

Accessory functions that are associated with respiration or accomplished with the aid of respiratory organs are: (1) production of sound; (2) elimination of volatile waste substances, such as water and acetone; (3) elimination of excess heat from the body.

STRUCTURE OF THE RESPIRATORY SYSTEM

The organs included in the respiratory system are the *air passage-ways* and the *lungs*.

Air Passageways. The following paragraphs describe the structure of the nasal cavities, paranasal sinuses, larynx, trachea, and the bronchi and bronchioles.

NASAL CAVITY. The nasal cavity occupies the space between the roof of the mouth and the floor of the cranial cavity. The nasal septum divides this space into the *right* and *left nasal fossae*, the external openings of which are the *external nares* or *nostrils*. Each nostril leads to a *vestibule*, the most anterior portion of the fossa, which contains long hairs called *vibrissae*. Posteriorly, the fossae open into the nasal portion of the pharynx through the *choanae* or *posterior nares*. Each

fossa is divided into the *respiratory* and *olfactory* regions, differentiated structurally on the basis of the type of epithelium lining them. The respiratory region comprises the major cavity of each fossa and serves as the main air passageway. The olfactory region, a relatively small area in the uppermost portion of each fossa, contains the olfactory receptors for the sense of smell.

Bony Structures of Nasal Cavity. The roof of the nasal cavity is supported as follows: (1) the anterior portion, by the nasal and frontal bones; (2) the middle portion, by the cribriform plate of the ethmoid; (3) the posterior portion, by parts of the sphenoid, vomer, and palatine. The floor is supported by the hard palate, composed of the palatal processes of the maxillae and the horizontal processes of the palatine bones. The nasal septum is formed by the vomer and the perpendicular plate of the ethmoid. The lateral walls of the nasal cavity are formed as follows: (1) the anterior portion, by the nasal and frontal bones and the maxillae; (2) lateral portion, by lateral mass of the ethmoid and the inferior conchae; (3) the posterior portion, by the vertical plate of the palatine and the medial pterygoid plate of the sphenoid. The medial surface of each lateral wall bears three prominent scroll-like projections, the *nasal conchae* or *turbinates*; the superior and middle conchae are inward projections of the lateral mass of the ethmoid bone, whereas the inferior conchae are independent bones. The conchae divide each fossa into three groove-like passageways, the *meatuses* (superior, middle, and inferior), which lie below and lateral to the corresponding conchae. Above and behind the superior conchae is the *sphenoethmoidal recess*.

Nasal Mucous Membrane. The nasal cavity is lined with mucous membrane which adheres closely to the periosteum of the underlying bone. It is continuous posteriorly with the mucous membrane of the nasopharynx and anteriorly with the modified skin lining the vestibules. It is also continuous with the mucous membrane which lines the paranasal sinuses.

The mucous membrane of the *respiratory region* (that covering the conchae and septum and lining the meatuses) consists of pseudostratified ciliated columnar epithelium containing many goblet cells. It rests on a prominent basement membrane which separates it from the underlying connective tissue (*tunica propria*). The latter contains numerous seromucous glands whose secretion serves to moisten the nasal surfaces. The epithelium of the *olfactory region* is pseudostratified columnar. It contains three types of cells: (1) *olfactory cells*, (2) *sustentacular* or *supporting cells*, and (3) *basal cells*.

The mucous membrane of the olfactory region contains the receptors for the sense of smell, which are stimulated by molecules of volatile substances present in the air. This membrane lies in the upper portion

of the nasal cavity, occupying an area on both sides of the nasal septum and on the superior conchae. The total area in each fossa amounts to about 250 sq. mm. The mucosa of this region differs from that of the respiratory region in the following respects: (1) ciliated cells are absent; (2) a basement membrane is lacking; (3) the glands are of a different nature; and (4) the color is yellowish instead of pinkish.

Blood, Lymph, and Nerve Supply of the Nasal Cavity. The respiratory epithelium throughout the nasal cavity is highly vascular, but on the surfaces of the middle and inferior conchae it is extremely so, containing numerous venous plexuses somewhat resembling erectile tissue. When these plexuses become engorged with blood, as in the nasal congestion which commonly accompanies respiratory infections, the mucosa becomes swollen and turgid, resulting in obstruction to the flow of air through the nasal passageways. Because of this extreme vascularity of the nasal mucosa, *epistaxis* (nosebleed) is common. This may arise from hypertension, trauma, abscesses, or ulcers.

The arteries supplying the nasal cavity are: (1) the *sphenopalatine*, a branch of the internal maxillary artery, which supplies the nasal conchae and the lower portion of the septum; (2) the *ethmoidal*, from the ophthalmic artery, which supplies portions of the lateral and medial nasal walls; (3) the *descending palatine*, from the internal maxillary artery, which supplies the floor of the nasal cavity; and (4) the *superior labial*, from the external maxillary artery, which supplies the vestibule. The ethmoidal arteries receive their blood through the internal carotid artery, the others through the external carotid.

The *venous plexuses* of the nasal mucosa are drained by (1) the *sphenopalatine* vein, which leads to the pterygoid plexus and thence into the common facial or exterior jugular vein; (2) the *ethmoidal* veins, which enter the ophthalmic vein and eventually drain into the cavernous sinus; and (3) branches of the *anterior facial* vein.

Lymphatics are numerous, draining into the subdural and sub-arachnoid plexuses.

The *olfactory nerves*, which pass through the cribriform plate, supply the olfactory epithelium. The respiratory epithelium is supplied principally by sensory fibers of the *trigeminal nerve*.

Functions of the Nasal Cavity. As air passes through the nasal cavity, it is warmed and moistened through contact with the mucous membrane. It is also filtered; larger, coarser particles are caught by nasal hairs, while smaller particles (such as dust and bacteria) are trapped by the sticky mucus, which is moved posteriorly by the currents which the cilia produce. A lapse of about ten minutes is required for mucus passing from the anterior portion of the nose to reach the pharynx, from which it is either expelled through the mouth or swallowed. The nasal cavity serves also as a resonating structure in the *production of sound*.

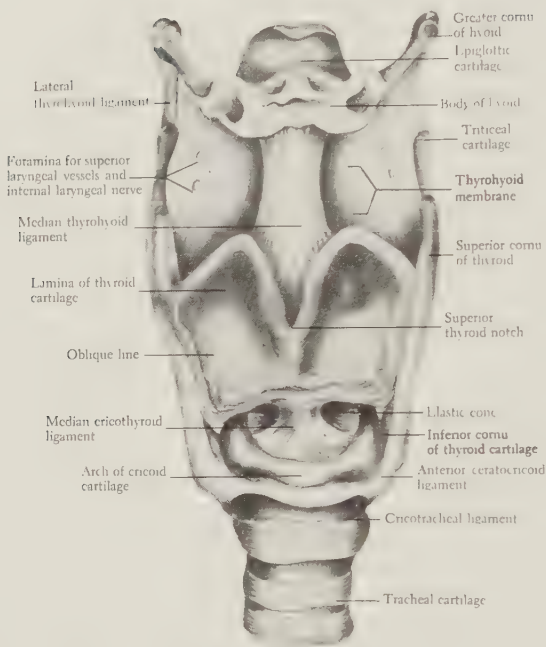


Fig. 2-1. Larynx, anterior view.

THE PARANASAL SINUSES. Air spaces present in bones adjacent to and communicating with the nasal cavity are referred to as the *paranasal sinuses*. The mucosa of these sinuses is continuous with that of the nasal cavity but is thinner and less vascular, hence paler in color. It is also less firmly attached to the adjacent bone structure. Mucous glands are present, and definite ciliated tracts convey the mucus through small channels into the nasal cavity. There are four groups of paranasal sinuses: the maxillary sinus or antrum of Highmore, the frontal sinus, the ethmoidal air-cells, and the sphenoidal sinus. The *primary function* of the paranasal sinuses is believed to be that of lightening the bones of the skull. *Secondary functions* are to supply mucus to the nasal cavity and to serve, along with that cavity, as resonating structures in sound production.

Maxillary Sinus or Antrum of Highmore. This is the largest of the paranasal sinuses, averaging 15–20 cc. in capacity. It is paired, being found in the body of each maxilla directly beneath the orbit. Each sinus opens into the middle meatus of the nose.

Frontal Sinus. This sinus lies in the frontal bone, superior and medial to the orbit. The frontal sinus, too, is paired, a frontal septum

separating the two sinuses. The shape of a frontal sinus is extremely variable. Often, the two sinuses are fused to form a single cavity; on the other hand, they may be subdivided to form several cavities. They may be large, small, or even lacking. Their average capacity is 7 cc. Each opens into the middle meatus.

Ethmoidal Air-Cells. These include numerous irregularly shaped air spaces which honeycomb the lateral masses of the ethmoid bone. Collectively, they form the *ethmoidal labyrinth*, which occupies the region between the orbit and the nasal cavity but may extend into the nasal conchae. The number of cells in each labyrinth varies from three to eighteen. The cells are arranged in three groups: (1) the *anterior ethmoidal cells*, numbering two to eight; (2) the *middle ethmoidal cells*, numbering one to six; and the *posterior ethmoidal cells*, numbering one to seven. The anterior cells communicate with the middle meatus, the middle cells with the anterior and posterior ethmoidal cells through large ostia, the posterior cells with the superior meatus.

Sphenoidal Sinus. This sinus, with its mate, lies in the body of the sphenoid bone. It varies greatly in size and shape, sometimes extending into the great wing. Its average capacity is 7–9 cc. Sphenoidal sinuses open into the sphenoidal recess.

Larynx. Between the pharynx and the trachea lies a tubular structure, the *larynx*, which serves to connect these two organs. It contains a pair of *vocal folds*, which regulate the passage of air through the larynx and play a role in the production of sound. For this reason, the larynx is commonly called the *voice box*. Lying in the neck, the larynx is anterior to the esophagus at about the level of the 4th to the 6th cervical vertebra. It is situated directly inferior to the hyoid bone, to which the larynx is firmly bound by the *hyothyroid membrane*. In swallowing movements, the larynx is drawn upward against the base of the tongue. This action causes the *epiglottis*, a cartilaginous flap lying superior to the larynx, to incline backward and downward, directing food into the esophagus and preventing its entry into the larynx.

STRUCTURE OF THE LARYNX. The larynx is made up of a number of cartilages bound together by an elastic membrane; its movement is controlled by muscles. Its lumen is lined with mucous membrane which is continuous with that of the pharynx above and the trachea below. The nine *cartilages* which form the framework of the larynx are:

| <i>Single</i> | <i>Paired</i> |
|---------------|---------------|
| Cricoid | Arytenoid |
| Thyroid | Corniculate |
| Epiglottic | Cuneiform |

The *cricoid cartilage* forms the lowermost portion of the larynx and is connected with the first tracheal cartilage. It is shaped somewhat

like a signet ring, the broad portion (*lamina*) being located at the back of the larynx, the narrow portion (*arch*) forming the anterior and lateral portions.

The *thyroid cartilage* is the principal cartilage of the larynx. It consists of two broad *laminae* united anteriorly to form a V-shaped structure which, in males, forms a more or less marked prominence called the "Adam's apple." The angle of fusion in males is approximately 90° , in females about 120° . Superiorly, the fusion is incomplete, leaving a V-shaped space between the laminae, the *superior thyroid notch*. On the posterior margins of each lamina are two projections, the *superior* and *inferior cornua*. The former is attached to the greater cornua of the hyoid by a ligament.

The *epiglottic cartilage* forms the framework of the epiglottis. It is a thin leaf-shaped cartilage lying above the thyroid cartilage and between the horns of the hyoid bone. Its upper end, which is slightly notched, is directed upward and posteriorly; its lower end narrows to a slender stalk, the *petiole*, to which the thyroepiglottic ligament is attached. To the lateral margins of the epiglottis are attached folds of mucous membrane, the *aryepiglottic folds*.

The *arytenoid cartilages* are two somewhat triangular-shaped cartilages lying directly superior to the cricoid cartilage, with which they articulate. The vocal ligaments, which lie in the free edges of the vocal folds, are attached to these cartilages. Movement of the arytenoid cartilages is largely responsible for changes in the state of tension of the vocal folds.

The *corniculate cartilages* are two small, conical structures located at the apices of the arytenoid cartilages.

The paired *cuneiform cartilages* are small, rounded bodies located in the aryepiglottic folds just anterior to the corniculate cartilages. They are somewhat variable in size and form, and they may even be absent.

The elastic membrane of the larynx consists of a sheet of elastic fibers forming a part of the walls of the larynx. Its upper portion is called the *quadrangular membrane*; the lower portion is called the *elastic cone*.

MUSCLES OF THE LARYNX. The muscles of the larynx comprise two groups: extrinsic muscles and intrinsic muscles. The *extrinsic muscles* are the muscles inserted on the larynx which have their origin on structures surrounding the larynx. They are involved in movements of the larynx *as a whole*, as in swallowing. Included in this group are the omohyoid, sternohyoid, sternothyroid, thyrohyoid, and several others. The *intrinsic muscles* lie entirely within the walls of the larynx. Their actions are concerned with movements of the *parts of the larynx with relation to each other*. They include the cricothyroid, thyroarytenoid

(external and internal), arytenoid (transverse and oblique), and crico-arytenoid (posterior and lateral).

The intrinsic muscles perform the following functions: (1) opening and closing the glottis during inspiration and expiration, (2) closing the laryngeal aperture and glottis during swallowing, and (3) regulating the tension of the vocal folds in the production of sound.

Both extrinsic and intrinsic muscles are composed of striated muscle fibers and are innervated by the superior portion of the *spinal accessory nerve* and the laryngeal branches of the *vagus nerve*.

LARYNGEAL CAVITY. The cavity of the larynx is relatively small. It contains within its walls two pairs of folds: the *ventricular folds* (false vocal cords) and the *vocal folds* (true vocal cords). The ventricular folds are two rounded folds, one lying on each side of the laryngeal cavity superior and parallel to the vocal folds. They are not concerned with sound production. The vocal folds are two white bands, each forming the edge of a prominence on the lateral wall of the larynx. They extend diagonally from the angle of the thyroid cartilage to the arytenoid cartilages. Each encloses the vocal ligament and vocal muscle, the internal thyroarytenoid. The vocal folds are the structures of the larynx primarily involved in voice production. The opening between them, which forms a narrow slit, is the *rima glottidis* or *glottis*.

The ventricular and vocal folds divide the laryngeal cavity into three regions: (1) the *vestibule*, the region superior to the ventricular folds; (2) the *ventricle*, the region between the ventricular and vocal folds; and (3) the *inferior entrance to the glottis*, the region lying inferior to the vocal folds.

The cavity of the larynx is lined throughout by mucous membrane which is continuous with that of the pharynx and the trachea. Its surface, except that covering the vocal folds, consists of pseudostratified ciliated epithelium containing many goblet cells. Mucous glands are abundant along with lymphatic tissue. The beat of the cilia is directed upward. Over the vocal folds the epithelium is stratified squamous, and cilia and glands are lacking. In this region there is little submucosa.

BLOOD AND NERVE SUPPLY OF THE LARYNX. The larynx receives blood through the *superior thyroid artery*, a branch of the external carotid, and the *inferior thyroid artery*, a branch of the thyrocervical trunk from the subclavian artery. Innervation is supplied by the *superior laryngeal nerve*, a branch of the vagus nerve, and the *inferior laryngeal*, a branch of the recurrent nerve which comes from the vagus. The larynx also receives sympathetic branches from the *thoracolumbar division* of the autonomic nervous system.

SEX DIFFERENCES IN STRUCTURE OF THE LARYNX. In boys and girls before puberty, the larynx is approximately the same size. After puberty, however, the larynx undergoes noteworthy changes in males: it

increases in size, the cavity becomes larger, the thyroid cartilage is more pronounced, and the vocal cords become longer and thicker. The result is a change in the quality and pitch of the voice. These changes are usually completed within two years.

LARYNX IN VOCALIZATION. The human voice consists of sounds produced by the vibration of the vocal folds and modified by the resonance chambers. Voice is produced by the passage of a current of air through the glottis. On the sides of the glottis are the parallel edges of the vocal folds (vocal cords) which, when possessing a certain degree of tension, vibrate and produce a sound. Immediately before speaking or before uttering any sound, one brings the edges of the vocal folds together. Contraction of the abdominal and thoracic muscles increases the air pressure in the lungs. When this pressure reaches a certain level, the glottis opens and the current of air passes out through the glottis, causing the vocal folds to vibrate, with the resultant production of a sound.

The changes in position and in tension of the vocal folds are brought about principally by the movement of two small triangular cartilages, the arytenoid cartilages, to which the posterior ends of the vocal folds are attached. The anterior ends of the folds are attached to the thyroid cartilage; the arytenoid cartilages can be made to rotate by the action of small muscles attached to them. Through the movement of these cartilages, the cords can be brought close together (which increases their tension and decreases the size of the glottis) or they can be moved outward toward the sides of the larynx (which decreases their tension and greatly widens the air passageway). In ordinary breathing, the cords occupy the latter position and no sound is produced. Muscle fibers in the cords themselves also play a role in increasing their tension.

Sound produced by the larynx alone would be crude, monotonous, and undifferentiated. Other organs and cavities of the skull must be brought into play in the production of articulate speech and musical tones. (For details of voice production, see page 47.)

Trachea. The windpipe or *trachea* is a tubular structure extending from the larynx downward through the neck into the thorax, where it terminates by dividing into the *right* and *left bronchi*, which lead into the lungs. It lies anterior to the esophagus. The trachea connects with the larynx at the level of the 6th cervical vertebra; its bifurcation is at about the level of the 5th thoracic vertebra. Within the thorax it lies in the mediastinum, its lower portion being directly posterior to the heart and the large blood vessels (arch of the aorta and the superior vena cava).

GROSS STRUCTURE OF THE TRACHEA. The wall of the trachea contains a series of 16 to 20 C-shaped cartilages which form its supporting framework. Each cartilage ring is incomplete dorsally, where the

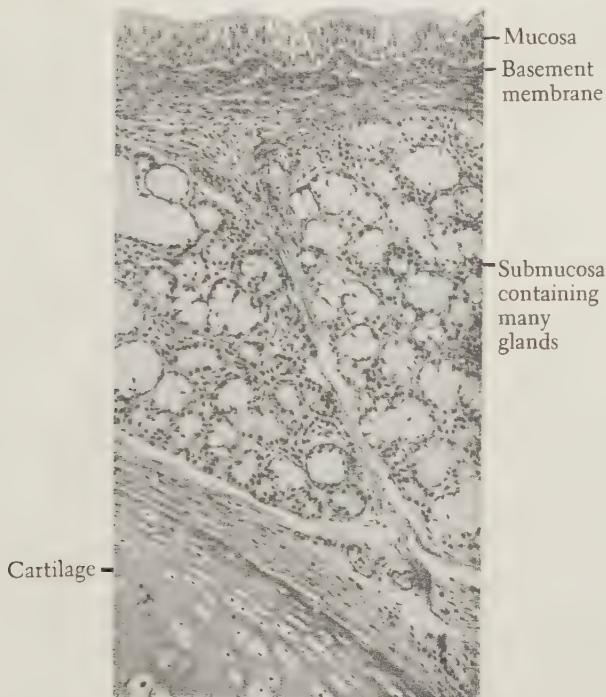


Fig. 22. Cross section through trachea. (Reprinted with permission of St. Martin's Press and The Macmillan Company, Ltd. from Hamilton, *Textbook of Human Anatomy*, 1957.)

trachea is adjacent to the esophagus. Across the open portion of each cartilage extends a fibro-elastic membrane containing fibers of smooth muscles which in general run transversely. The cartilages prevent the trachea from collapsing and thus maintain a free passageway for air.

MICROSCOPIC STRUCTURE OF THE TRACHEA. The trachea consists of four layers: mucosa, submucosa, cartilage layer, and adventitia. The *mucosa* forms the innermost layer; it is lined with ciliated pseudostratified columnar epithelium containing many goblet cells. The beat of the cilia is upward. The *submucosa* consists principally of loose connective tissue containing many *tracheal glands*, compound tubulo-alveolar glands, which secrete mucus. These open onto the surface of the mucosa. The *cartilage layer* consists of a layer of hyaline cartilage, with smooth muscles stretching between the ends of the cartilages. The *adventitia* consists of dense connective tissue containing elastic and reticular fibers; it is continuous with the surrounding connective tissue.

Bronchi and Bronchioles. These are the tubes that convey air from the trachea to the alveolar sacs of the lungs. At about the level of the

manubrium of the sternum, the trachea bifurcates into two branches, the *right* and *left primary bronchi*, each of which follows a diagonal course to the lungs. The right primary bronchus is the shorter and wider of the two (it is about 1 inch in length); the left primary bronchus measures about 2 inches in length and lies more horizontally than does the right. For this reason, foreign bodies drawn into the trachea enter the right bronchus more frequently. Each of the bronchi is similar in microscopic structure to the trachea; the right bronchus possesses six to eight rings of cartilage, and the left has nine to twelve rings.

On entering the hilus of the lung, each bronchus divides into smaller bronchi (two in the left lung, three in the right), which enter the primary lobes of the lung. Within the lung these smaller bronchi divide and subdivide into still smaller bronchi, the diameter decreasing with each subdivision. The cartilage rings of the bronchi become progressively smaller and eventually are replaced by irregularly distributed cartilage plates, which also gradually decrease in size. When the air tubes acquire a diameter of about 1 mm., the cartilage disappears and the tubes are known as *bronchioles*. The branch entering a lobule is called an *intralobular bronchiole*. This branches into *terminal bronchioles*, each of which gives rise to two or more *respiratory bronchioles*. The last named then branch into *alveolar ducts*, which lead to the *alveolar sacs*. Each of these sacs (also called "air sacs") has numerous outpocketings, the *alveoli*.

As the cartilage in the bronchial tube grows less abundant, the amount of smooth muscle tissue increases, becoming most prominent in the terminal bronchioles, where it is intimately associated with the elastic layer, forming a *myoelastic layer*. In the respiratory bronchioles, the ciliated columnar epithelium of the conducting tubes undergoes transition to the cuboidal type, and goblet cells become fewer. Distally the cilia disappear and, in the alveolar sacs, the epithelium becomes of the simple squamous type, adapted for ready passage of gases to and from the surrounding capillaries.

The smooth muscles of the bronchioles are innervated by constrictor fibers of the vagus nerve and dilator fibers of the sympathetic trunk. Thus the diameters of the bronchioles are adjusted reflexly to the respiratory needs of the body.

Lungs. The lungs are the primary organs of respiration. They serve essentially as structures which permit the interchange of gases (oxygen and carbon dioxide) between the blood and the air.

The lungs, the right and left, lie in the thoracic cavity, one on each side of the mediastinum. Each is roughly cone-shaped, with its *base* resting upon the diaphragm, its tip or *apex* extending superiorly into the root of the neck. On the medial surface of each lung is a depression, the *hilus*. At this point several large structures enter or leave the

lung, among them the bronchi, the pulmonary artery and veins, the bronchial arteries and veins, lymphatic vessels, and nerves. Collectively, these structures constitute the *root of the lung*. Each lung lies free in the thoracic cavity, attached only by its root and by a pulmonary ligament.

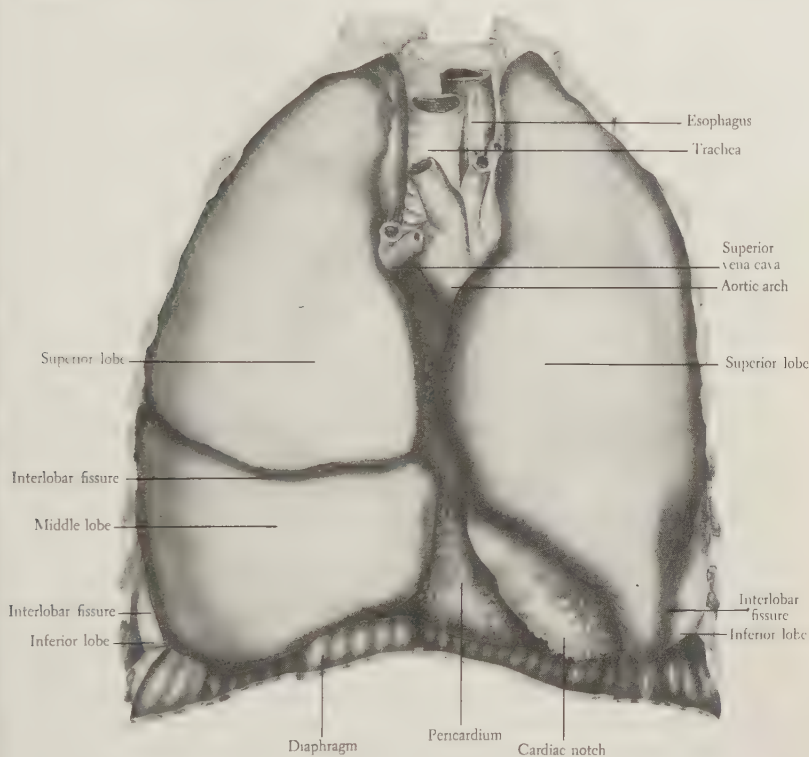


Fig. 2-3. The lungs.

SURFACES OF THE LUNGS. Each lung possesses three surfaces: costal, diaphragmatic, and mediastinal. The *costal* surface lies against the thoracic wall; the *diaphragmatic* (the base) rests against the diaphragm; the *mediastinal* is directed medially and bears a concavity, the *cardiac fossa*, which accommodates the heart.

LOBES OF THE LUNGS. Each lung is divided by a deep *interlobar fissure* into two lobes; a *superior lobe* and a larger *inferior lobe*. In the right lung, however, a secondary fissure, located below the interlobar fissure, extends horizontally and gives rise to a third or *middle lobe*.

GROSS STRUCTURE OF THE LUNGS. The right and left lungs are slightly *asymmetrical*, the right being shorter and broader owing to

is the *primary lobule*, consisting of a terminal bronchiole and the air ducts connected with it (respiratory bronchioles, alveolar ducts, alveolar sacs, and alveoli) together with its associated blood vessels, lymphatics, and nerves. In addition to the lobes, each lung is further subdivided into segments (apical, posterior, superior, anterior, and lateral) as portions of the bronchial tree.

BLOOD AND LYMPH SUPPLY OF THE LUNGS. The principal blood vessels supplying the lungs are the bronchial and pulmonary arteries. The *bronchial arteries* arise from the aorta or from an intercostal artery. There are two for the left lung, one for the right lung. They enter at the hilus and follow the bronchi and their branches, terminating at the distal ends of the alveolar ducts. These arteries supply oxygen and nourishment for the lung tissue. Bronchial veins from the lung tissue terminate in the innominate, azygos, intercostal, or pulmonary veins. *Pulmonary arteries* also enter each lung at the hilus and follow the main bronchus, with branches accompanying the successive divisions of the bronchial tubes. On entering a pulmonary lobule, a branch accompanies each alveolar duct and terminates in a capillary net in the walls of the alveoli. Here the deoxygenated blood from the tissues is separated from the alveolar air only by the capillary wall and the thin wall of the alveolus. This arrangement permits the ready diffusion of gases between the alveolar air and the blood in the capillaries. Venules from the alveolar capillaries and from those of the pleura lead to larger veins which, in turn, lead to the *pulmonary veins* (two for each lung), which make their exit from the hilus. The latter, carrying oxygenated blood, empty into the left atrium.

Lymph vessels are present in the walls of the bronchi, pleura, and pulmonary arteries and veins. Lymph nodes are found at the branching of the larger bronchial tubes. Nodules of lymphoid tissue are found along the pulmonary vessels. These frequently contain considerable quantities of carbonaceous material, especially in advanced age.

Thoracic Cavity. The thoracic cavity is the space lying within the walls of the thorax, its floor being formed by the diaphragm which separates it from the abdominal cavity. Superiorly, the thoracic cavity extends a short distance into the base of the neck.

DIVISIONS OF THE THORACIC CAVITY. Two pleural cavities, right and left, contain the lungs. The region between these pleural cavities is known as the *mediastinum* or *mediastinal septum*.

The Pleurae. Enclosing the lungs is a serous membrane called the *pleura*, which forms a closed doubled-walled sac consisting of two layers. The *pulmonary pleura* or *visceral layer* closely invests the lungs, covering almost their entire surface. The *parietal layer* forms the lining of the thoracic wall, lying against the endothoracic fascia. It may be differentiated into costal, mediastinal, diaphragmatic, and cervical re-

gions. The *isthmus* is the portion connecting the visceral and parietal pleurae. It forms a tube-like structure investing the structures which constitute the root of the lung.

The space between the visceral and parietal layers is a potential rather than a real cavity, for expansion of the lungs causes the visceral layer to come into contact with the parietal layer, from which it is separated by a very thin space filled with serous fluid. This fluid serves for lubrication, permitting free movement of the lungs within the thoracic cavity.

Mediastinal Septum. Between the two pleural cavities lies the *thoracic mediastinum* or *mediastinal septum*, which contains the organs and structures occupying the interpleural space. These are:

1. The heart and its pericardial covering.
2. The great vessels entering and leaving the heart (thoracic aorta and branches from the aortic arch, pulmonary artery, superior vena cava, and thoracic portion of the inferior vena cava).
3. The thymus gland.
4. The esophagus and the lower portion of the trachea.
5. The thoracic duct and thoracic lymph nodes.
6. Nerves passing into or through the thorax, including the vagi, phrenic, recurrent laryngeal, and cardiac nerves.

THE PHYSIOLOGY OF RESPIRATION

External respiration or breathing has two aspects: *inspiration*, the taking in of air, and *expiration*, the expulsion of air. It is accomplished through changes in size of the thoracic cavity brought about by the contraction and relaxation of respiratory muscles. The thoracic cavity is a closed space, having no external openings. Contained within it are the lungs, elastic bag-like structures that communicate with the outside by means of the respiratory passageways. When the thoracic cavity enlarges, a reduction in pressure causes the air to rush in and fill the lungs. When the inspiratory movements cease, the size of the thoracic cavity is reduced and the resultant increase of pressure on the lungs causes the air to be expelled.

Pressure Changes. The pressure within the thoracic cavity, that is, between the two layers of pleura, is known as *intrapleural* or *intra-thoracic pressure*. It is always slightly less than atmospheric pressure (a "negative pressure"), which is due primarily to the elasticity of the lungs. If an opening is made in the thoracic wall, air will enter the pleural cavity and the lung will collapse.

The pressure within the lungs and the respiratory passageways is *intrapulmonary pressure*. When it is below atmospheric pressure, inspiration occurs; when it is above atmospheric pressure, expiration takes place. The movement of air into and out of the lungs is due to

changes in intrathoracic pressure, which, in turn, causes changes in intrapulmonary pressure.

Respiratory Movements and Rate of Respiration. The rhythmic movements of the thorax by which air is drawn into and expelled from the lungs constitute the respiratory movements. With inspiration and expiration counted as one combined movement, the normal rate in quiet breathing is about 14 to 18 a minute. This rate is, however, variable. It is increased by muscular activity, by higher body temperatures (as in fever), and in certain pathologic conditions (such as hyperthyroidism). It varies between the sexes, women having the more rapid rate (16 to 20 per minute), and with age, the approximate rates being as follows: at birth, 40 to 60; at 5 years, 24 to 26; at 15 years, 20 to 22; finally, at 25 years, 14 to 18. The *position of the body*, too, has an effect on the rate of respiration, which drops to 12 to 14 when the body is prone or during sleep. With the body in a semi-erect position or in a sitting position, the rate increases to about 18; with the body in a standing position, the rate is 20 to 22. *Emotional conditions*, too, may slow down or speed up the rate.

The Types of Respiration. The following terms describe various types and conditions of breathing.

Apnea. Temporary cessation of breathing movements.

Dyspnea. Difficult or labored breathing, usually accompanied by discomfort and the sensation of breathlessness.

Eupnea. Normal breathing, with usual quiet inspirations and expirations.

Hyperpnea. Increase in depth of breathing; abnormal exaggeration of respiratory movements.

Orthopnea. Dyspnea when body is in a horizontal position. It is usually relieved upon the assumption of an upright position.

Polypnea. Rapid breathing such as results from increased activity or from emotional states; a common symptom is "panting."

Tachypnea. Excessively rapid and shallow breathing.

Muscular Activity in Breathing. As previously stated, changes in pulmonary pressure are directly responsible for determining whether air will flow into or out of the lungs, and these changes are brought about by changes in the size of the thorax. These latter changes are accomplished through the action of the respiratory muscles, which include the diaphragm, abdominal muscles, and various muscles that act on the ribs.

INSPIRATION. The *diaphragm* is a dome-shaped muscle which forms the floor of the pleural cavities, separating them from the abdominal cavity. Contraction of the radial muscle fibers causes the diaphragm to become slightly flattened and to descend. This increases the vertical diameter of the thorax and reduces intrathoracic and intrapulmonary

pressures so that air from the outside, having a higher pressure than that in the lungs, rushes into these organs. In its descent, the diaphragm exerts a pressure on the abdominal contents, causing them to press against the abdominal muscles. Being generally relaxed, these muscles give way, and the abdominal wall moves outward. This process is known as *diaphragmatic breathing*, or as "abdominal" breathing.

The chest cavity can also be enlarged by raising the sternum and the ribs. This process is called *costal* or *thoracic breathing*. The ribs extend laterally from the vertebral column with their curved anterior ends extending downward and forward. Contraction of the *external intercostal muscles* elevates the anterior ends of the ribs, especially the 3rd to 6th pairs, and these ends move upward and outward. Since they are attached to the sternum through the costal cartilages, the sternum, too, moves forward and upward. These actions increase the anteroposterior and lateral diameters of the thorax. In forced respiration, additional muscles may assist the external intercostals in this elevation of the ribs and sternum; these are the *scaleni*, *levatores costorum*, *pectoralis major*, and *serratus posterior superior*.

EXPIRATION. Normal, quiet respiration is a *passive process*. No active muscular effort is expended. At the end of inspiration, the diaphragm and the external intercostals relax. The recoil of the stretched costal cartilages and the weight of the walls of the thorax, together with the recoil of the elastic lungs, act to bring the chest wall back to its original position. The relaxed diaphragm moves upward as a result of the pressure of the abdominal contents and the negative pressure within the thoracic cavity. Intrathoracic pressure is increased, and air is expelled from the lungs.

In forced, or labored, respiration, such as occurs during strenuous muscular activity or during voluntary deep breathing, expiration is an *active process* involving the activity of a number of muscles. The muscles primarily involved are: the *abdominal muscles* (rectus abdominis, external and internal oblique, transverse abdominis), which constrict the abdominal cavity, causing pressure to be exerted on the under side of the diaphragm; and the *internal intercostals*, *serratus posterior inferior*, and *quadratus lumborum*, which depress the ribs.

Respiratory Sounds. Passage of air through the air passageways to the alveoli produces sounds which can be heard through the stethoscope or by applying the ear to various regions of the thorax.

NORMAL SOUNDS. The normal sounds are: the *bronchial* or *tubular sound*, a high-pitched sound heard principally over the trachea, bronchi, and larger bronchioles, occurring in both inspiration and expiration; and the *vesicular murmur*, a soft, rustling sound heard only during inspiration and at the beginning of expiration, thought to be caused by the distention of the alveoli with air.

ABNORMAL SOUNDS. Obstruction of the respiratory passageways, such as occurs in pathologic conditions, results in marked changes in respiratory sounds; hence these sounds play an important role in the diagnosis of pulmonary disorders. The term *rale* is applied to an abnormal sound arising in the lungs or air passageways and heard on auscultation of the chest. It results from the passage of air through bronchial tubes containing a secretion of exudate or narrowed by a spasm or a swelling of their walls. Various terms are applied to different types of rales, such as "crepitant," "fine," "medium," "coarse," "moist," and "dry." *Wheezing* refers to a whistling or sighing sound. Alterations in normal breathing sounds or the appearance of sounds not normally heard occur in diseases such as pneumonia, tuberculosis, and asthma. Other sounds of importance in the diagnosis of respiratory disorders are the *pleural friction sound*, *voice sound*, and *percussion sounds*. The pleural friction sound occurs when the roughened surfaces of the pleura rub against each other, as in pleurisy. The whispered voice sets up sounds in the chest which are useful in detecting the presence of pulmonary infiltration. Percussion sounds (those resulting from tapping the chest) indicate by their degree of resonance various chest conditions. If the air of the lung is replaced by fluid or solid substance as in pneumonia, a short, feeble high-pitched sound technically known as *dull* or *flat* is produced instead of the normal sound designated as *normal* or *vesicular resonance*.

Respiratory Volumes. The amount of air that can be taken into and expelled from the lungs can be measured with a *spirometer*. The volumes determined are classified as *tidal volume*, *expiratory reserve volume*, and *inspiratory reserve volume*.

TIDAL VOLUME. This is the amount of air inhaled and exhaled during normal quiet breathing. It averages about 500 ml. for the adult male. Of this amount, about 150 ml. remains in the respiratory passageways; this is *dead space air* which is unavailable for respiratory exchange. The remainder (350 ml.) constitutes *alveolar air*.

INSPIRATORY RESERVE VOLUME. This is the maximum amount of air that, in addition to tidal air, can be inhaled after an ordinary expiration that has followed a normal inspiration. For an adult male, this averages about 3000 ml.

EXPIRATORY RESERVE VOLUME. This is the amount of air that can be expelled by the most forceful effort after an ordinary expiration that has followed a normal inspiration. For an adult male, this averages about 1000 ml.

VITAL CAPACITY. The total of tidal, inspiratory reserve and expiratory reserve volumes constitutes *vital capacity*. This is the amount of air that can be expelled by the greatest effort following the deepest

possible inspiration. It averages 4500 ml. for the average adult male. This measurement serves as an index to the general physical fitness of an individual; it is higher in athletes and others engaged in strenuous physical activity, lower in persons leading a sedentary life. Improper posture, lung disease, obesity, and deformities of the thorax or abdomen are among the conditions which decrease vital capacity.

VITAL CAPACITY. The total of tidal, inspiratory reserve, and expiratory. It averages 2500 ml. per sq. meter of body surface for men, 2000 ml. for women, 2800 ml. for athletes.

RESIDUAL AIR. This term refers to the air that remains in the lungs after the most forcible expiratory effort. It averages about 1500 ml. Even in case of a collapse of a lung, which occurs when the thorax is opened, some air remains trapped in the alveoli and the lung will float in water. This is also called *minimal air*. It is of importance in medico-legal cases, since its presence or absence is the criterion for determining whether or not a baby is stillborn (fetal lung tissue sinks when placed in water).

The following table shows graphically the relationships just described, as applied to the *average adult male*:

| | | | | | |
|---------------------------------------|----------------------------|----------------|---------|----------|-------------------------------|
| TOTAL LUNG CAPACITY 6000 ml. | Tidal volume | Alveolar air | 350 ml. | 500 ml. | Vital capacity 4500 ml. |
| | | Dead Space Air | 150 ml. | | |
| | Inspiratory reserve volume | | | 3000 ml. | 1500 ml. |
| | Expiratory reserve volume | | | 1000 ml. | |
| | Residual air | | | | |

Exchange and Transport of Gases in Respiration. In the lungs, oxygen is taken up by the blood and carbon dioxide is given off. In its passage throughout the body, the blood surrenders the oxygen to the tissues and takes on the CO_2 .

CHEMICAL CHANGES. The following table shows the chemical changes that take place in the air *within the lungs*:

| Gases | Inspired Air | Expired Air | Alveolar Air |
|-------------------------------|--------------------|-------------|--------------|
| | (Volumes Per cent) | | |
| Oxygen | 20.96 | 16.3 | 14.2 |
| Carbon dioxide | .04 | 4.0 | 5.5 |
| Nitrogen and other rare gases | 79. | 79.7 | 80.3 |
| Water vapor | low | high | high |

MECHANICS OF EXCHANGE OF GASES. Within the body the movement of gases is governed by the same physical laws that govern the movement of gases outside the body. The principal process involved is *diffusion*. This, briefly, is the tendency which the molecules of a gas have to become uniformly distributed. When there are differences in pressure or tension, that is, differences in the number of molecules per

unit of space, the gaseous molecules tend to move from a region of higher tension to one of lower tension. In a mixture of gases, each gas acts independently of the others.

When air is drawn into the lungs in a normal inspiration, the lungs are only partly filled with fresh air, since this tidal air amounts to only one-eighth of vital capacity. But diffusion occurs, oxygen diffusing from the alveoli into the blood and carbon dioxide in the reverse direction. In respiration, with fresh air being repeatedly drawn into the lungs, this process is taking place continuously.

Diffusion in the Alveolar Walls. In the alveolar walls, diffusion of gases takes place between the alveolar air and the blood. About 5 liters of blood is pumped through the lungs each minute. In the capillaries of the lungs, this blood is brought into close relationship with the alveolar air, from which it is separated by the extremely thin membranes of the capillaries and the alveolar walls. (Some histologists maintain that the alveoli lack a complete epithelial lining, in which case only the thin endothelium of the capillary would separate the blood from the air in the alveoli.) It is estimated that the capillary surface within the lungs (that is, the surface over which the blood is exposed to the alveolar air) exceeds 1000 sq. ft. The differences in pressure of oxygen and carbon dioxide in blood leaving the lungs and blood being brought into them are as follows:

| | Arterial Blood | Mixed Venous Blood | Difference |
|----------------|-------------------|-----------------------|------------|
| | (mm. of mercury) | | |
| Oxygen | 100 | 40 | 60 |
| Carbon dioxide | 40 | 46 | 6 |

As a result of the foregoing differences of pressure, oxygen diffuses from the alveoli of the lungs into the blood, and carbon dioxide diffuses from the blood into the alveoli. *In the tissues*, the process is reversed. Oxygen tension in the tissues is low, owing to the continuous use of oxygen in the oxidative processes of metabolism, and carbon tension is high, owing to the continuous production of that compound in the same process. As a result of these differences in tension, oxygen diffuses from the blood into the tissues, and carbon dioxide diffuses from the tissues into the blood.

Transport of Oxygen by the Blood. Oxygen is carried in the blood in two forms: (1) in solution in the plasma, a negligible amount (only about 3 per cent) being carried in this form; and (2) in combination with hemoglobin, as oxyhemoglobin.

When the blood is fully oxygenated, each 100 ml. of blood contains approximately 20 ml. of oxygen. Under normal conditions, arterial blood is 95-97% saturated and contains (per 100 ml.) 19 ml. of

oxygen (18.7 ml. in the red blood cells in combination with hemoglobin; 0.30 ml. in the plasma in solution).

Oxygen combined with hemoglobin forms an unstable chemical compound called *oxyhemoglobin*. Such hemoglobin is said to be "oxygenated" rather than oxidized, for no oxide is formed. When oxyhemoglobin gives up its oxygen, it is referred to as *reduced hemoglobin*.

At rest, the body uses about 250 cc. of oxygen per minute. The total oxygen capacity of *all* the blood is roughly 1000 cc., which amount is consumed in about four minutes when at rest or within one minute during strenuous activity. There is *no mechanism for storage of oxygen*.

The quantity of oxygen that can be held as oxyhemoglobin in red blood cells depends on the partial pressure of the oxygen being held in solution in the plasma, which, in turn, depends on the pressure of oxygen in the alveolar air of the lungs or in the tissue fluids or tissue cells. In the lungs the partial pressure of oxygen is approximately 100 mm. Hg. At this pressure the blood takes on oxygen and the hemoglobin becomes about 95 per cent saturated. In the tissues and the tissue fluids, the oxygen pressures are much lower (30 mm. Hg.); consequently, in the tissues, oxygen is given up by the hemoglobin.

Factors which favor the dissociation of hemoglobin (i.e., the giving up of oxygen) are: low oxygen pressures, relatively high carbon dioxide pressures, a rise in temperature, and an increase in hydrogen-ion concentration. The last two reduce the quantity of oxygen that the blood will hold at any given pressure. In muscular activity, a local rise in temperature (resulting from increased oxidations) and an increased hydrogen-ion concentration (resulting from production of carbon dioxide and lactic acid) favor the greater release of oxygen to the tissues.

Hemoglobin can transport oxygen only when it is contained within the red blood cells. If hemoglobin is released into the circulating fluid, as occurs in hemolysis, it is quickly lost through three processes: excretion by the kidneys, destruction by the cells of the reticuloendothelial system, and conversion into a brown pigment, *methemoglobin*. The latter occurs after poisoning by certain substances such as acetanilid and phenacetin.

Transport of Carbon Dioxide by the Blood. The amount of CO_2 in arterial blood varies from 44 to 52 volumes per cent, the average being 49 cc. per 100 cc. of blood. The carbon dioxide content of venous blood ranges from 50 to 80 volumes per cent. About 5 per cent of the total CO_2 is carried in solution in the plasma; the remainder is in chemical combination with the various constituents of the blood in the plasma and the red blood cells. Of this remaining 95 per cent, about 8 cc. per 100 cc. of blood is in combination with hemoglobin as *carbohemoglobin*, and 87 cc. per 100 cc. is in the form of carbonates, bicarbonates, and carbonic acid.

Only a small part of the carbon dioxide carried by the blood is actually combined with hemoglobin, but, through the release of its alkali, the hemoglobin is involved indirectly in the carriage of over 85 per cent of the blood CO_2 .

Chloride Shift. An increase in the carbon dioxide content of the blood brings about an increase in the bicarbonates which increase the alkali reserve. For this reason, even though large quantities of CO_2 can be taken up by the blood, the blood reaction (pH) will change very little, if at all. As carbon dioxide increases in the blood, the concentration of sodium bicarbonate (NaHCO_3) increases. The source of the Na^+ ions is the sodium chloride (NaCl) of the plasma; the bicarbonate ions (HCO_3^-) come from the carbonic acid and carbonates within the red blood cells. The chloride ions (Cl^-), left free from the NaCl giving up its Na^+ ions, shift from the plasma to the cells, where they combine with potassium. This mechanism is known as the *chloride shift*. In the lungs, the reverse process occurs. When CO_2 is given off, HCO_3^- ions move into the cells and Cl^- ions move out into the plasma.

Control of Respiratory Muscles. Respiratory movements are essentially involuntary. This is somewhat anomalous, since the respiratory muscles are principally striated and therefore subject to voluntary control. Consequently, although respirations occur automatically, one can at will speed up, slow down, or even stop respiration for a limited time (generally about 45 seconds).

Respiratory Center of the Brain. The control of the rate and depth of breathing movements is lodged in the *respiratory center* of the brain. This comprises groups of nerve cells located in the medulla oblongata and in the midbrain. Automatic involuntary respiratory movements are due to the rhythmic discharge of nervous impulses from this center. These impulses pass down the spinal cord to motor neurons in the 3rd, 4th, and 5th cervical segments, whose axons conduct the impulses out of the spinal cord and through the *phrenic nerves* to the diaphragm. Each phrenic nerve is a branch of the cervical plexus; it passes downward through the thorax to reach the diaphragm. Efferent impulses from the respiratory center may also descend to the motor neurons of the 3rd to the 6th thoracic segments, where they pass through peripheral nerves to the intercostal muscles, or they may pass to other respiratory muscles, such as those in the nostrils, pharynx, and larynx.

REGIONS OF THE RESPIRATORY CENTER. The respiratory center includes three regions: an inspiratory center, an expiratory center, and a pneumotaxic center. All three are bilateral. The first two are located in the medulla, the third in the midbrain. The *inspiratory center* sends out impulses which bring about contraction of inspiratory muscles.

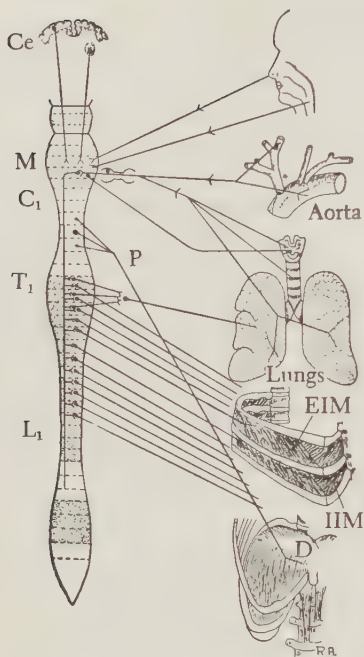


Fig. 2-5. Nervous control of respiration. (Ce), cerebral cortex; (C₁), spinal cord at first cervical level; (D) diaphragm; (EIM and IIM) external and internal intercostal muscles; (L₁) spinal cord at first lumbar level; (M) medulla; (P) phrenic nerve; (T₁) spinal cord at first thoracic level. Nerves to abdominal muscles are not shown. (Reprinted with permission of The Macmillan Company from Kimber, et al., *A Textbook of Anatomy and Physiology*, 13th ed., 1955.)

The *expiratory center* discharges inhibitory impulses to the inspiratory center which stop the outflow of inspiratory impulses; when this occurs, inspiration ceases and expiration follows automatically, and is thus passive in nature. The function of the *pneumotaxic center* is not well understood, but it is thought that it plays a role in the inhibition of inspiration.

FACTORS INFLUENCING THE RESPIRATORY CENTER. While respiratory movements are rhythmic and automatic, their rate and degree (that is, whether deep or shallow) can be altered readily. These changes are brought about by certain factors which influence the respiratory center. The automaticity of this center is thought to be due to its capacity to send out impulses as a result of changes occurring within the center itself in the same way that the heart beat is initiated by factors operating within the heart tissue itself. The factors referred to are chemical, physical, and nervous.

Chemical Factors. The roles of carbon dioxide, hydrogen-ion concentration, and oxygen in the activity of the respiratory center are described in the paragraphs that follow.

Carbon dioxide plays a dominant role in the regulation of respiratory movements. It stimulates the respiratory center, increasing the rate by (1) acting directly on the center and (2) stimulating sensory chemo-

receptors in the carotid body and the aortic arch. Any condition which only slightly increases the carbon dioxide tension of alveolar air, which, in turn, increases carbon dioxide tension in the blood, brings about increased respiratory activity.

Voluntary forced breathing for three or four minutes (*hyperventilation*) is followed by a period of apnea which lasts 40 to 60 seconds. This is due to depletion of CO_2 , which is demonstrated by the fact that if a subject performs this same experiment but breathes into a paper sack, thereby rebreathing the same air, apnea does not occur. It is also known that forced breathing, if continued for a prolonged period of time, will bring on dizziness and possibly "blackout" (loss of consciousness). All these are consequences of depletion of the carbon dioxide content of the blood.

Hydrogen-ion concentration acts in the same way and has the same effect on respiration as CO_2 . There is a close relationship between the pH of the blood and the carbon dioxide content, for an increase in the latter increases the carbonic acid content.

Oxygen content variations are of little consequence in the regulation of normal breathing movements. When, however, oxygen lack becomes pronounced, as at high altitudes (above 10,000 feet), the chemoreceptors of the carotid body and the aortic arch are stimulated and respirations are increased reflexly. Oxygen content of the air may be reduced by one-half without affecting the rate of respiration. Nor does oxygen excess have any effect on the rate of respiration. Breathing pure oxygen does, however, have a detrimental effect on the body, causing development of lesions of the lungs. An oxygen concentration of 60 to 70 per cent is the maximum that can be breathed for any length of time with safety.

Physical Factors. Physical factors influencing the activity of the respiratory center include: temperature, blood pressure, and air pressure within the lungs.

An *increase in body temperature*, as in fever or during muscular activity, increases the respiratory rate; a *reduction* below normal is accompanied by a reduced rate of respiration. A *fall in blood pressure* increases the respiratory rate; a *rise* in this pressure decreases the rate. Blood pressure acts on the pressure receptors of the carotid sinus and the aortic arch, affecting the respiratory center reflexly. *Inflation of the lungs* is a primary factor in the regulation of normal breathing movements. As the lungs become inflated during inspiration, the expansion of the alveoli stretches the lung tissue and stimulates sensory receptors (proprioceptors). This initiates a stream of impulses which pass over afferent nerves (the vagi) to the respiratory center in the brain. These impulses have an inhibitory effect which decreases the activity of the center, bringing about cessation of inspiration. Expiration, as already

stated, follows automatically. The action just described is known as the *Hering-Breuer reflex*.

Nervous Factors. Nervous control of respiratory movements falls into two categories: voluntary control and reflex control.

Voluntary control is accomplished through impulses discharged from the higher centers of the brain, that is, the cerebral cortex. Normal rhythmic respiratory movements can be altered at will. They may be speeded up, slowed down, or stopped completely for a limited time. Voice control, as in speaking or singing, and straining movements, as in defecation, involve alterations in respiratory movements, and these are principally under voluntary control. Emotions, too, have a marked effect on the rate and depth of respiration. In fright or excitement, respirations are accelerated; under conditions of suspense, apprehension, or close attention, they may become slow and shallow. The sigh of disappointment, the spasmodic breathing of laughter, the gasp of astonishment, and the sobbing which accompanies grief are manifestations of the effects of emotions on respiration.

RESPIRATORY REFLEXES

| <i>Receptor</i> | <i>Stimulus</i> | <i>Effect on Respiration</i> |
|--|--|--|
| <i>Proprioceptor endings in:</i> Lungs | Stretching of alveoli and bronchioles | Inhibits or ends inspiration |
| Carotid sinus and Aortic arch Pharynx | Rise of blood pressure Fall of blood pressure Presence of food or saliva | Decreases rate Increases rate Stops inspiration and closes glottis |
| Joints | Bending | Increases rate |
| <i>Chemoreceptor endings in:</i> Carotid body and Aortic arch Olfactory epithelium and Respiratory passageways | CO ₂ excess, extreme O ₂ lack, H-ion increase Presence of obnoxious gases, dust, infectious organisms | Increases inspiratory rate Stops inspiration, initiates coughing reflex |
| <i>Somatic afferent endings in:</i> Skin Any sense organ | Cutaneous stimuli (including cold or pain) Usual stimuli intensified | May inhibit or stimulate inspiration May inhibit or stimulate inspiration |
| <i>Visceral afferent endings in:</i> Internal organs | Pain or pressure | May inhibit or stimulate inspiration |

Involuntary control is accomplished through reflexes. It is responsible not only for normal, quiet breathing, but also for the responsiveness of the respiratory mechanism in adjusting to the varying needs of the body. These reflexes are summarized in the table on page 44.

Asphyxiation. Because the primary function of respiration is the conversion of venous or deoxygenated blood into arterial or oxygenated blood, the mechanisms that control it are very sensitive to changes in the chemical nature of the blood. When any condition arises which interferes with gaseous exchanges in the lungs (for example, strangulation, drowning, or the presence of an obstruction in the respiratory passageways), the blood becomes more venous; that is, its oxygen supply is diminished and its carbon dioxide supply is increased. When such a condition prevails, the respiratory center is stimulated both directly and indirectly, and respiratory movements become more rapid and forceful. This condition is referred to as dyspnea or "labored" breathing. If the cause of the dyspnea is not removed, the respiratory center is stimulated to greater activity. The respiratory muscles contract more vigorously and the accessory muscles, especially those involved in expiration, become more active. Soon nearly all the muscles of the body are thrown into a state of convulsive activity. With the onset of these convulsions, a state of *asphyxia* sets in. In a short time the muscles become exhausted, inspirations are fewer in number and become progressively weaker, and, finally, a last inspiration is taken and breathing ends with an expiratory gasp.

Death from asphyxiation is brought on by two conditions: lack of oxygen, and acidosis resulting from an accumulation of carbonic acid in the blood. Oxygen starvation and carbonic acid poisoning are both injurious to the tissues; of the two, the former, also called *anoxia*, is probably the primary factor.

INTERNAL RESPIRATION

The exchange of oxygen and carbon dioxide between the blood and the body cells and the utilization of oxygen by the cells constitute *internal* or *cellular respiration*. Oxygen combines in the tissues with many substances; the final products are carbon dioxide and water. Through oxidative processes, the major portion of the energy needed for bodily activities is released. The rate of oxidation in any tissue is an index of *vital activity*. Cessation of oxidations results in death of the tissue or the organism. The amount of oxygen used by the tissues depends on the type of tissue and the extent of its activity. Muscles and glands consume the greatest quantities of oxygen. In a resting state, oxygen consumption is low; during activity, it is greatly increased.

Nature of Tissue Oxidation. Fundamentally, oxidations occurring within the body are similar to those occurring outside the body, in that

oxygen combines with a substance, which is consumed, and waste products are produced. However, when a substance is burned in air, the rate and extent of combustion are determined by the supply of oxygen and the rate of removal of waste products. In living tissues, the rate of combustion is carefully controlled to meet the needs of the organism. Besides, in the body cells, foodstuffs do not unite directly with oxygen; instead, they are broken down, step by step, to simpler products (metabolites), and intermediate products become progressively richer in oxygen. The final products are CO_2 and water. In this long series of chemical reactions, all of which take place at a relatively low temperature (about 99°F.), catalysts (enzymes and coenzymes) are essential, each step requiring a specific catalyst.

The following processes are regarded as oxidations: (1) addition of oxygen, (2) withdrawal of hydrogen (dehydrogenation), and (3) loss of electrons. The reverses of these processes are considered to be *reductions*. All three types of oxidations are alike in that there is loss of one or more electrons from the substance oxidized.

ENZYME SYSTEMS. The enzymes which catalyze oxidations of foodstuffs, all of which are intracellular enzymes, fall into two groups: dehydrogenases and oxidases. *Dehydrogenases* are enzymes that act to withdraw hydrogen from food molecules; they catalyze reactions in which hydrogen is given up. *Oxidases* are enzymes that serve as oxygen activators; they catalyze reactions in which hydrogen is oxidized to water by molecular oxygen.

Some of these enzymes consist of a protein component and a non-protein component, both of which are essential to the reaction being catalyzed. The protein portion is usually referred to as the "enzyme"; the nonprotein portion is called the "coenzyme." When both of these components are working together, they constitute an "enzyme system."

THE CYTOCHROME SYSTEM. In cellular oxidations, an important enzyme system is the *cytochrome system*, which consists of a cytochrome oxidase and three pigments: cytochromes a, b, and c. These red, iron-containing compounds, present in cells, serve to make oxygen available for the oxidation of hydrogen liberated from cellular metabolites by the dehydrogenases.

VITAMINS. An important group of enzymes are the *flavoprotein enzymes*. Flavins are yellowish pigments found in nearly all cells. One of them, lactoflavin, which has been isolated from milk, seems to be identical with riboflavin (also called vitamin B_2), which is essential to cellular oxidations. In addition to riboflavin, two other vitamins, *nicotinic acid* and *thiamin*, play a role in the oxidative processes. Like riboflavin, nicotinic acid enters into the structure of flavoproteins. Thiamin serves as a coenzyme.

Inhibition of Tissue Respiration. Certain substances, in particular *cyanides*, have the ability to unite with the iron-containing enzymes, inactivating them and inhibiting cellular respiration. This ability accounts for their extreme deadliness.

PHYSIOLOGY OF VOICE PRODUCTION

Language is the mechanism by which man communicates ideas and expresses feelings; *speech* is a highly developed form of language in which thoughts and feelings are expressed by articulate sounds. *Voice* is the purposive production of sound by means of the respiratory organs. Paradoxically, the voice may consist of "voiceless" sounds (such as whispers, produced merely by the movement of a column of air through the air passageways) or "voiced" sounds produced by the vibrations of the vocal folds.

The human voice has certain fundamental properties which are characteristic of all sounds, namely: intensity or loudness, timbre or quality, and pitch (highness or lowness). *Intensity* depends on the amplitude of the vibrations, which, in turn, depend on the force of the column of air that moves past the vocal cords. *Timbre* depends on the number and intensity of the overtones or harmonics, which are determined principally by the shape and size of the resonating chambers. *Pitch* depends primarily on the length, tension, and thickness of the vocal cords; these factors affect the frequency of the vibrations of the cords. Since women and children have shorter vocal cords than men, their voices are more highly pitched. Although innate structure largely predetermines the nature of the foregoing properties for individuals, intensity, timbre, and pitch are all subject to variation through voluntary control of the muscles of the respiratory organs.

Mechanics of Voice Production. The human voice mechanism is similar in many respects to most tone-producing musical instruments. It consists of a *vibrator* or source of sound, a *motor* or force for setting the vibrator in motion, and a *resonator* or amplifier which reinforces certain vibrations. In the human voice mechanism, the vocal folds (true vocal cords), located in the larynx, serve as the vibrator. The force which sets them to vibrating is the breath exhaled from the lungs, which strikes the tense vocal cords as it makes its exit from the chest cavity. The resonator consists of a number of parts (the pharynx, mouth, and nasal cavities) which function in the amplification of the tone initiated by the vocal folds.

The human voice mechanism differs from most tone-producing instruments, however, in that it has, in addition, a series of *articulators* which modify the tone into specific speech sounds; these articulators are the lips, teeth, tongue, and hard and soft palates, and the parts which form the walls of the resonating cavities.

The production of a speech sound is accomplished in the following manner: After an inhalation, the vocal folds of the larynx are approximated and made tense by the action of the intrinsic muscles of the larynx. Upon exhalation, the air under pressure passes through the narrow glottis. When it strikes the tense vocal folds, these are set into vibration, giving rise to a sound wave and the production of a more or less undifferentiated vocal tone. The sound wave set in motion by the vocal cords passes upward and enters the resonating chambers, where it is amplified and, finally, by the action of the walls of these chambers and by the articulators, is modified and refined in quality. The amplified and modified sound wave then assumes the characteristics of a specific speech sound.

The resonating cavities, along with the articulating parts, serve to (1) reinforce the sound that was initiated by the vocal cords, (2) give quality to it by the selection of harmonic overtones, and (3) produce the differentiated vowels and consonants. Some of the parts are *static*, or fixed; others, such as the soft palate and uvula, tongue, lips, teeth, and cheeks, are *mobile*. Malformations of any of these structures may cause marked modifications in the quality of the voice, as is indicated in speech defects caused by harelip, cleft palate, absence of teeth, or the presence of adenoids.

In the production of vowels, the resonating tube (especially the lips) assumes a specific form for each vowel sound. Consonants are produced by interrupting the passage of the air column at some point in the expiratory pathway; they are called "labial," "dental," "palatal," "stopped," "nasal," "open," or "guttural," depending on the site and manner of their formation.

Nervous Mechanism of Speech. The development of speech depends on the association of sounds (words) with sensations (visual, tactile, etc.) aroused by objects in the external environment. Impulses arising from these stimuli pass to the association regions of the brain where they are "stored" as memories. For example, the word "cat" when heard brings to mind a mental image or picture of that animal. Talking or *verbal expression of an idea* consists essentially of (1) co-ordination of sensory impulses in the association centers of the cerebrum and (2) transmission of impulses from these centers to the muscles of respiration and the muscles of the larynx and other structures that are involved in the production of speech. Learning to read consists of associating the visual symbols of speech (words) with auditory symbols (spoken words). Learning to write consists of expressing auditory and visual impressions by means of the coordinating action of the digital muscles with cerebral impulses. Association centers for the understanding of spoken or written symbols have not been definitely localized; instead, they seem to be rather widely distributed

over the cortex of the left cerebral hemisphere. For left-handed persons, these centers are in the right hemisphere.

Defects of Speech. Speech is considered to be defective when it deviates from the normal to extent that it is noticeable and interferes with ordinary communication. Defective speech often leads to severe personality maladjustment. Speech defects fall into four general classes:

DEFECTS OF RHYTHM. Stuttering, stammering, and cluttering are defects of rhythm in speech. They are characterized by repetitions of words or phrases or the first sounds or syllables of words. The speech becomes hesitant, and stoppages occur. Such defects may be accompanied by facial contortions and spasms and by abnormal respiratory movements.

DEFECTS OF ARTICULATION. These are characterized by distortions of speech sounds. Included are "baby talk," lalling (pronouncing *r* so that it sounds like *l*), lisping (*th* for *s* or *z*, and *w* for *l*), and delayed speech.

DEFECTS OF PHONATION. These include aphonia (lack of voice), pitch disorders (monotone, too high pitch, or too low pitch), and disorders in voice quality (hypo- or hypernasality).

DEFECTS OF SYMBOLIC FORMULATION AND EXPRESSION (DYSPHASIA). Rather than being defects of the organs that produce speech, these arise from disorders in the higher brain centers. *Aphasia* is the inability to use words as symbols of ideas. Aphasia may be motor, sensory, or both. In *motor aphasia* (*Broca's aphasia*), the subject, although unable to speak or write normally, is still capable of understanding what is said and is able to read; there is no paralysis of the muscles of articulation. In *sensory or receptive aphasia*, the subject, though able to hear and see, is unable to understand spoken words (*word deafness*) or written words (*word blindness*), but retains the ability to speak and to write. In *total aphasia*, disturbances in both the sensory and the motor spheres preclude all these activities. *Anarthria* (loss of speech) and *dysarthria* (difficult speech) are terms applied to disorders of speech due to paralysis of the muscles involved in articulation. These are usually the result of lesions of the brain or conditions involving the muscles.

PRACTICAL CONSIDERATIONS

Artificial Respiration. When respiratory movements have ceased temporarily, as in cases of drowning, electrical shock, or asphyxiation, they may be restored through artificial respiration. The objective of all methods of artificial respiration is to keep air moving into and out of the lungs until the respiratory center recovers and becomes capable of initiating respiratory movements. If the oxygen supply to the tissues

is cut off for a period of more than four to five minutes, irreparable damage is done to the central nervous system, with little hope of recovery. But if the heart is still beating and the blood circulating, resuscitation is possible. There are manual, mechanical, and electrophrenic methods of artificial respiration.

MANUAL METHODS OF ARTIFICIAL RESPIRATION. The manual methods of restoring spontaneous breathing movements, listed in the order of their effectiveness, are:

Arm-Lift and Back Pressure (Nielsen Method). The operator kneels at the head of the prone subject (lying face down) and alternately raises the patient's arms and applies pressure to the upper part of the thorax.

Hip-Lift and Back Pressure. The operator kneels on one knee astride the prone subject at the level of the subject's hip and alternately raises the hips and applies pressure to the back.

Hip-Roll and Back Pressure. Similar to the hip-lift and back pressure method, except that when the operator raises the subject's hips he rolls them to one side and then applies pressure to the back.

Arm-Lift and Chest Pressure (Sylvester Method). The operator kneels at the head of the supine (face upward) subject, whose arms are then alternately extended above the head and folded across the chest with pressure applied.

Chest Pressure (Howard). The operator kneels at the side of (or astride) the supine subject and, with hands on the subject's chest near the costal border, applies pressure on the chest and then rocks backward.

Prone Pressure (Schafer). The operator kneels astride one or both of the prone subject's legs and, with hands placed over subject's floating ribs, rocks forward and backward rhythmically, applying pressure to the back.

Experimental studies have shown that the *push-pull methods*, the first four in the list, are more than twice as effective for pulmonary ventilation as the *push-only methods*, the last two. The Nielsen method has been proved to be the most effective of all, and has been adopted by the American Red Cross and the United States armed services, as well as by most of the public health agencies throughout the United States.

Another manual method requires the employment of a board. This is the *Eve rocking method*, in which the subject is placed on the board and alternately tipped up and down, teeter-totter fashion. The up-and-down movements of the viscera push and pull the diaphragm up and down. Small children can be rocked in the arms of the operator.

Still another nonmechanical method is *mouth-to-mouth respiration*, in which the operator expires slowly and with moderate pressure di-

rectly into the subject's mouth or nose, then removes his own mouth and allows the patient to breathe out passively.

MECHANICAL METHODS. If artificial respiration must be carried on for long periods of time, perhaps days, weeks, or even months, mechanical methods are used. They are employed in cases wherein the respiratory center fails to function, in spinal cord injuries, or in paralysis of the respiratory muscles as in poliomyelitis. The apparatus most commonly used is the Drinker mechanical *iron lung*. The patient is placed in a hermetically sealed cabinet and air pressure within the cabinet is alternately increased and decreased by a motor-driven pump. Another apparatus, a mechanically operated rocking bed that works on the principle of the Eve rocking method, has recently come into use.

ELECTROPHRENIC METHOD. In this method, the phrenic nerves are stimulated by an electric current of the proper strength, duration, and frequency. Because the respiratory movements are, though indirectly, initiated by nerve impulses, this method of artificial respiration most closely simulates normal breathing.

Modified Forms of Respiration. Forms of inspiration or expiration which are either spasmodic, exaggerated, voiced, or otherwise radically different from normal breathing are essentially modified forms of respiration. Examples are: coughing, sneezing, hiccoughing, snoring, yawning, sighing, crying, and sobbing.

COUGHING. A cough is a violent expiration preceded by an inspiration of greater than normal depth. The muscles of expiration, especially the abdominal muscles, contract suddenly and the closed glottis increases the intrathoracic pressure. The partial opening of the vocal cords allows air to rush out with hurricane force, and the resultant action on the vocal cords produces a sharp sound. Coughing serves a protective function in that it provides a means for dislodging foreign particles from the respiratory passageways and ejecting them from the body. Coughing is commonly initiated by any irritation of the respiratory mucosa, such as occurs in respiratory infections. But stimulation of other parts of the body or psychic factors may also induce a cough.

SNEEZING. A sneeze, too, is a sudden violent expiration, with the air being discharged through the nasal cavities. It is a reflex action, usually resulting from irritation of the nasal mucosa, but it may be induced by other stimuli, such as suddenly directing a bright light into the eye.

HICCOUGHING. This modified form of respiration results from sudden contraction of the diaphragm, the inspiration being cut off by quick closure of the glottis. It is reflex in nature, being initiated by stimulation of the afferent nerve endings in the diaphragm. It is com-

mon in infants, distention of the stomach probably being the causative factor. Hiccoughing may also result from a lesion in the respiratory center or along its afferent or efferent pathways.

SNORING. The production of coarse breathing noises during sleep or while in coma is due to the vibration of the soft palate and/or the uvula.

YAWNING. A yawn (induced by boredom or weariness) is a long, deep inspiration with the mouth open wide, followed by a slow expiration.

SIGHING, CRYING, SOBBING. These forms of respiration are automatic, rhythmic reactions to physical or psychic stimuli, such as disappointment, sorrow, grief, and pain.

Principles of Room Ventilation. Prolonged breathing of air in a poorly ventilated room eventually brings on discomfort; a feeling of stuffiness and oppression develops, vitality is reduced, and headache may ensue. Contrary to popular belief, these symptoms are not due to lessened oxygen supply or increased carbon dioxide consumption. The former may be reduced to 14 per cent (normal amount, 21 per cent) and the latter increased to 6 per cent (normal amount, 0.04 per cent) before noticeable effects develop. Even in the most poorly ventilated room, changes of this kind do not occur. Investigations have disclosed that the ill effects of poor ventilation are due principally to changes in the temperature and moisture content of the air, with a consequent loss of cooling power. Proper ventilation of a room requires that the air (1) be clean, that is, relatively free of dust and bacteria; (2) possess the proper amount of moisture; (3) have the proper temperature; and (4) be kept in constant circulation.

Formerly it was thought that in crowded rooms poisonous substances discharged from the lungs and skin exerted certain toxic effects. While occasionally volatile substances, such as acetone, may appear in the breath, there is no evidence that these or other gaseous substances discharged by expiration have any harmful effects on other persons who breathe the same air. Infectious bacteria may, however, be present on the minute droplets of moisture that are discharged by coughing or sneezing. It is believed that most of the communicable diseases are transmitted in this way.

Halitosis. The production of foul odors in the breath may result from respiratory infections or bacterial decomposition taking place in the mouth or the respiratory passageways, or from ingestion of certain odoriferous foods. *True* or *essential halitosis* is caused by faulty metabolism of fats in which noxious volatile substances enter the circulating blood and are excreted through the lungs.

Effects of Increased Air Pressure. Persons who work under abnormally high air pressure (divers, workers in diving bells or caissons)

sometimes experience a condition known as *caisson disease* or *decompression sickness*. Under high air pressure, the blood and tissues absorb extra quantities of the gases in the air (nitrogen, oxygen, carbon dioxide). This does not prove harmful if the internal and external pressures remain constant. But if the individual passes too rapidly from a region of high pressure to one of low pressure, serious effects ensue. The excess nitrogen in the blood is released in the form of small bubbles, which accumulate in the tissues and the blood vessels, giving rise to such symptoms as nausea, dizziness, muscular pains, abdominal cramps, and pains in the joints. The last of these symptoms has given the condition its popular name—the *bends*. The symptoms can be avoided or relieved by passing the patient through a series of “decompression chambers” by means of which the outside pressure is reduced gradually. This permits blood gases to come slowly to an equilibrium with the atmospheric gases.

Anoxia (Hypoxia). Any condition in which the tissues fail to receive an adequate supply of oxygen leads to *oxygen want* or *anoxia*. Anoxia may be *local*, as occurs when an organ or tissue is deprived of its blood supply; or it may be *general*, as occurs when the oxygen supply of the blood is reduced (*anoxemia*).

There are four types of anoxia, shown with causative factors in the table which follows:

CAUSES OF ANOXIA

| <i>Type</i> | <i>Primary Causative Factor</i> |
|-------------|--|
| Anoxic | Low oxygen tension in inspired air |
| Stagnant | Slow circulation of blood, either local or general |
| Anemic | Oxygen-carrying capacity of blood below normal |
| Histotoxic | Disturbance in oxidative mechanism in tissues |

Anoxic Anoxia. This is the condition in which the blood, in passing through the lungs, fails to acquire its normal oxygen saturation (95 per cent). It may be due to: low oxygen tension of the atmospheric air, as in high altitudes; vitiated air, as in mines; interference with the air supply to the lungs, as from obstruction of the respiratory passages by a foreign object; or reduced alveolar surface, as in tuberculosis. Anoxic anoxia that occurs at high altitudes is called *mountain sickness*. The first symptoms of this begin to appear at about 10,000 feet, at which point oxygen saturation of hemoglobin is about 85 per cent and dyspnea, nausea, vomiting, and cyanosis develop. There may also be emotional disturbances (instances of faulty judgment are common). At extremely high altitudes, consciousness may be lost. The symptoms disappear on return to lower altitudes. The body is capable, however, of adjusting in time to the rarefied atmosphere of high altitudes (up to 20,000 feet). Constant exposure results in an increased chest volume

and an increased number of red blood cells, which may reach 6 to 8 million per cu. mm.

Stagnant Anoxia. This condition results from a slowing down of blood circulation through the tissues. It occurs when blood pressure becomes excessively low, as in cardiac insufficiency, or when circulatory collapse occurs as in shock.

Anemic Anoxia. When the oxygen-carrying capacity of the blood is reduced, anemic anoxia results. It may be caused by a reduction in the number of red cells or a reduced amount of hemoglobin (as occurs following a severe hemorrhage or in anemia), or by the inability of hemoglobin to carry oxygen. The last of these occurs in carbon monoxide poisoning. Hemoglobin has a greater affinity for carbon monoxide than for oxygen; consequently, small quantities of carbon monoxide in the atmosphere (as little as 0.2 per cent), when breathed for some time, may cause death. When this gas combines with hemoglobin, a relatively stable compound, *carboxyhemoglobin* (COHb) is formed, which prevents hemoglobin from uniting with oxygen. Death results from oxygen deprivation.

Histotoxic Anoxia. In this condition the oxidative processes within the tissues are depressed or abolished. It occurs in cyanide poisoning, in which the enzyme systems within the cells are inactivated, thus inhibiting cellular oxidations.

Oxygen Therapy. In the treatment of certain types of anoxia, the administration of oxygen has proved to be of considerable value. It is employed in cases of pneumonia or pulmonary edema, when the alveolar surfaces for diffusion of oxygen are much reduced. It is also used in the treatment of pulmonary tuberculosis, certain types of asphyxiation, poisoning by narcotics, and congestive heart failure. It is not effective in the treatment of anemia. The oxygen may be administered through an open cone or a nasal catheter, or in an oxygen chamber or *oxygen tent*. The concentration of oxygen in the oxygen tent or chamber is maintained at between 40 and 60 per cent. Sometimes, carbon dioxide in a concentration of 5 to 10 per cent is administered along with the oxygen, to stimulate the respiratory center.

DISEASES AND DISORDERS OF THE RESPIRATORY SYSTEM

Adenoids. An inaccurate term which refers to hypertrophy of the pharyngeal tonsils, located in the posterior portion of the nasal cavity. "Adenoids" may obstruct the nasal passages, causing mouth breathing. In some cases, serious consequences may result, such as retarded physical and mental development.

Asthma. Paroxysmal attacks of dyspnea accompanied by abnormal breathing sounds. Asthma is characterized by a spasm of the muscles in the bronchial tubes or edema of (or excessive secretion of mucus by) the mucous mem-

branes. Either condition obstructs the respiratory passageways. In the majority of cases, it is believed to be a manifestation of an allergic reaction. It is treated with such drugs as epinephrine, ephedrine, and atropine, which act through the autonomic nervous system, relaxing the smooth muscle tissues. Asthma may have a psychogenic origin, in which case psychotherapy is resorted to.

Bronchiectasis. Dilation of a bronchus or a bronchiole, usually accompanied by accumulation of pus, giving rise to paroxysmal coughing and expectoration of mucopurulent matter.

Consolidation. Accumulation of matter in the air spaces of the lungs.

Croup. A condition frequently seen in children, characterized by dyspnea, laryngeal spasm, and sometimes, formation of a false membrane.

Diphtheria. An acute infectious disease, a toxemia caused by the Klebs-Loeffler bacillus. It is characterized by the formation of a false membrane on the mucous surfaces of the throat and by extreme prostration. The latter symptom is due to the effects of a toxin secreted by the bacillus.

Emphysema. Distention of the tissues by gas or air, or overdistention of the alveoli and the bronchial tubes.

Empyema. Presence of pus in a body cavity, especially the pleural cavity.

Hay Fever. An allergic disease affecting the mucous membranes of the nose, other upper respiratory passageways, and the conjunctiva of the eye. It may be caused by inhalation of foreign substances, such as pollen or dust.

Pleurisy. Inflammation of the pleura, the membrane that lines the thoracic cavity and covers the lungs.

Tonsillitis. Inflammation of the tonsils, also referred to as *quinsy*. Peritonsillar tissue may become involved, with resultant abscess formation.

Tuberculosis. An infectious disease caused by an acid-fast bacterium, *Mycobacterium tuberculosis*. It is characterized by the formation of tubercles in the tissues. Any organ may be affected: lungs, bones and joints, kidneys and bladder, or lymph glands. It may be localized or general. *Pulmonary tuberculosis* is the most common form. The *primary* or first-infection type (childhood tuberculosis) results in enlargement and calcification of lymph nodes in the region of the hilus of the lung. Constitutional symptoms are few and vague. The disease is considered to be noninfectious in this stage. The *secondary* or reinfection type (adult tuberculosis) involves the lungs, usually the apices, and results in the formation of cavities. This is the so-called *active tuberculosis*, the infective organisms of which can be readily transmitted. Treatment is usually prolonged and sanatorium care is recommended. Special methods of treatment for resting the lung include: *artificial pneumothorax* (injecting air into the thoracic cavity), *phrenectomy* (cutting) or *phrenicotripsy* (crushing) of the phrenic nerve, and *thoracoplasty* (removal of portions of the ribs).

Whooping Cough (Pertussis). An infectious disease characterized by recurrent attacks of coughing which end in a "whooping" respiration. It is caused by the Bordet-Gengou bacillus. Whooping cough is frequently fatal to very young infants.

SPECIAL TERMS

Cyanosis. Bluish coloring of the mucous membranes and skin owing to the presence in the capillaries of excessive amounts of reduced hemoglobin (hemoglobin from which oxygen has been removed). It is associated with the anoxic

and stagnant types of anoxia, previously described. Cyanosis may be due to (1) incomplete oxygenation of blood in the lungs (*arterial* or *central cyanosis*), (2) slow circulation through the capillaries (*peripheral cyanosis*), or (3) alterations in the hemoglobin, such as the production of methemoglobin or sulf-hemoglobin resulting from intoxication by sulfanilamide, aniline, and other substances.

Pneumothorax. Accumulation of air or gas in the pleural cavity. This condition may be induced deliberately (artificial pneumothorax) in the treatment of pulmonary tuberculosis.

Tonsillectomy. Removal of the pharyngeal tonsils. The radical method is by surgery; the conservative method is by diathermy (electrical coagulation).

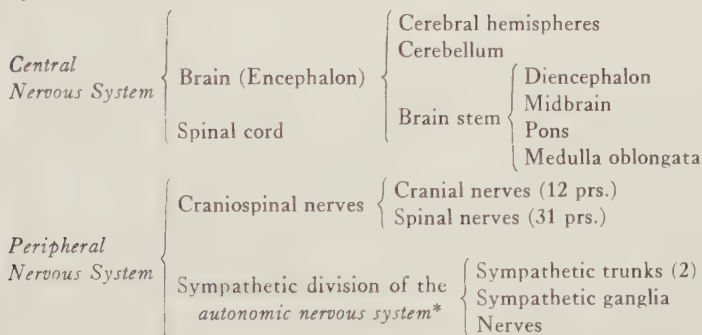
Tracheotomy. Surgical measure in which an incision is made into the trachea and a metal tube is inserted into the opening to serve as an air passageway. It is resorted to in cases of obstruction of the passageway (as in cancer of the larynx and in diphtheria) or presence of a foreign body.

3: THE NERVOUS SYSTEM

The nervous system is the stimulus-response mechanism of the organism. The cells and nerve fibers which comprise it form an interconnecting network that links every part of the organism. The very fact of living implies stimulation and response, and it is the function of the nervous system to coordinate the activities of the body in stimulus-response relations—that is, in response to internal and external environmental conditions.

ORGANIZATION OF THE NERVOUS SYSTEM

The nervous system comprises the *brain*, *spinal cord*, *ganglia*, and *nerves*. The structural unit is a specialized type of cell, a *neuron*. The functional unit is a group of two or more neurons, constituting a *reflex arc*. This system has two divisions, the central and the peripheral. The *central nervous system*, made up of the brain and the spinal cord, is contained within the cranial cavity of the skull and the vertebral canal of the spinal column. The *peripheral nervous system* includes all nervous structures (ganglia and nerves) which lie outside the cranial cavity and the vertebral canal. The following is a schema of the nervous system:



* The term "autonomic nervous system" is a functional rather than an anatomic one. This system includes all structures (ganglia and nerves) that innervate the involuntary organs (viscera, smooth muscles, cardiac muscles, glands).

FUNCTIONS OF THE NERVOUS SYSTEM

The primary function of the nervous system is *regulation and coordination of body activities*. This system is the seat of consciousness,

memory, and intelligence. It provides the basis for such higher mental processes as reasoning, thinking, and judgment. The central nervous system is also the center of emotional responses.

All activities of the body are adjustments of the organism to a changing environment. Changes are constantly occurring outside the body in the *external environment*, and within the body in the *internal environment*. Nerve cells (receptors) respond to these changes (stimuli), and a wave of irritability sweeps over the nerve cell. This constitutes a *nerve impulse*. Because all parts of the organism are connected through the nervous system, an impulse may be conducted to any or all parts of the body. Upon reaching organs such as muscles or glands, the impulse may induce activity (contraction of the muscle or secretion by the gland). An effect is produced; therefore, these organs are known as *effectors*. Through the responses of effectors the organism adjusts itself to environmental conditions.

HISTOLOGIC STRUCTURE OF THE NERVOUS SYSTEM

Nervous tissue consists of nerve cells, or *neurons*, and supporting cells, or *neuroglia*.

Neurons. A neuron consists of a central portion, or *cell body* (*perikaryon*), which bears one or more cytoplasmic projections called *cell processes*.

CELL BODY. The cell body consists of a nucleus and cytoplasm.

Nucleus. The *nucleus* is a large, spherical structure usually centrally located. Within its nuclear membrane is a linin network, but basic-staining chromatin is scanty. A large *nucleolus* is usually present, and adjacent to it is a minute *nucleolar satellite*. The nucleus has a characteristic vesicular appearance.

Cytoplasm. The *cytoplasm* surrounding the nucleus contains a number of structures. Among them are (1) neurofibrils and interfibrillar substance, (2) chromophil substance, (3) Golgi apparatus, (4) mitochondria, and (5) inclusions. A centrosome may be present in immature cells. The undifferentiated portion of the cytoplasm is called *neuroplasm*. The *neurofibrils* are slender, delicate fibrils forming an interlacing network in the cell body. They extend into the axon and dendrites, where they assume a parallel position until they terminate. They are thought to function in the conduction of impulses. The *chromophil substance* consists of fine granules which, when clumped together, form bodies of various shapes called *Nissl bodies* or *tigroid bodies*. They are scattered throughout the cytoplasm and occur in the dendrites of the larger neurons. They are absent in the axon and axon-hillock. Nissl bodies are involved in protein synthesis and in protein utilization which occurs during activity of the cell. Following prolonged activity or in pathological conditions, there is a reduction

in the amount of Nissl substance, a condition known as *chromatolysis*. The *Golgi apparatus*, characteristic of nerve cells, usually appears as a coarse, irregular network. It undergoes changes in pathological conditions and following nerve cell injury. Its function is unknown. Both the Golgi bodies and *mitochondria* (protein and lipid filaments) appear to be concerned with metabolism in the cell. *Inclusions* consist primarily of nonliving granules and crystals.

CELL PROCESSES. Neurons have two kinds of processes: *dendrites* and *axons*.

Dendrites. These are short processes which branch in tree-like fashion. They are naked; that is, they lack a myelin sheath and neurilemma. Short projections called *gemmules* may protrude from their surface. A neuron may possess one or many dendrites.

Functionally, dendrites always conduct impulses to the cell body. In some neurons, such as sensory neurons, whose cell bodies lie in the spinal ganglia, typical dendrites are lacking, and impulses are conducted to or toward the cell body through the medium of a single process which has the structure of an axon; such processes are called *axon-like dendrites*.

Axons. These processes, also referred to as *axis cylinders*, vary in length; some are very short, but others measure up to 3 feet or more in length. They are of uniform diameter and usually bear side processes called *collaterals*. Axons are usually enclosed in one or more sheaths, a myelin sheath or a neurilemma or both. Axons end in terminal arborizations called *telodendria* which, both in the central nervous system and in ganglia, make connections (synapses) with the cell bodies or dendrites of other neurons. Peripherally, axons terminate in autonomic ganglia or effector organs.

NERVE FIBERS AND THEIR SHEATHS. Nerve fibers are axons or axon-like dendrites. They are widely distributed in the body but concentrated in nerves, the spinal cord, and brain. They usually possess a myelin sheath or a neurilemma or both.

The *myelin sheath*, consisting chiefly of lipid substances, is highly refractive and gives to nerves their whitish appearance. It is not continuous but is interrupted at intervals by constrictions, the *nodes of Ranvier*. It serves as an insulating layer.

The *neurilemma* or *sheath of Schwann* is a delicate tubelike membrane which closely invests the myelin sheath. On its inner surface lie the *cells of Schwann*, whose radiating bands of cytoplasm form a protoplasmic network lining the sheath. The neurilemma and Schwann cells are essential for the regeneration of nerve fibers. They are present in fibers of peripheral nerves but not in those of the brain and the spinal cord.

Fibers which lack both of these sheaths are known as *naked fibers*.

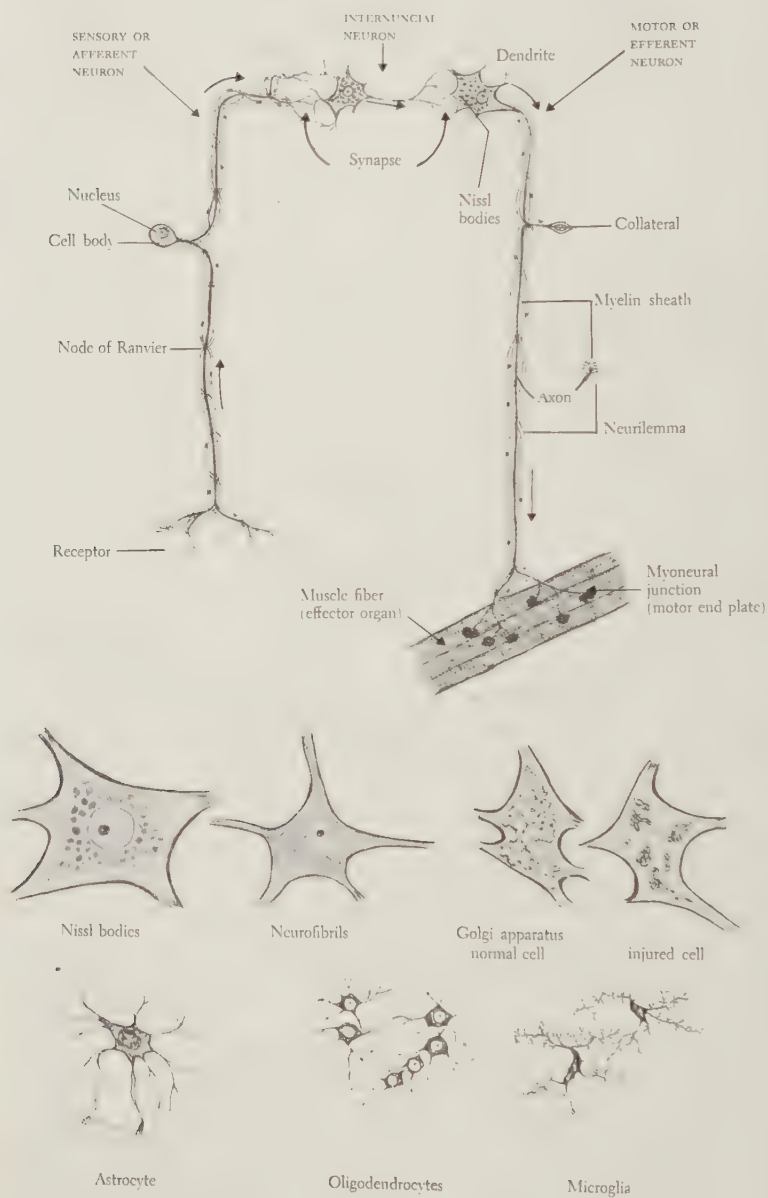


Fig. 3-1. Types of neurons and neuroglia cells.

Amyelinated (non-medullated, gray, or Remak's) *fibers* lack a myelin sheath but possess a neurilemma; *myelinated* (medullated, white) *fibers* may or may not possess a neurilemma. It is lacking in fibers of white matter of the brain.

CLASSIFICATION OF NEURONS. Neurons can be classified in two ways: (1) on the basis of the number of processes, and (2) on the basis of function.

1. *On the Basis of the Number of Processes.* Neurons are unipolar, bipolar, or multipolar.

Unipolar neurons have only one process. Sensory neurons of cranial and spinal ganglia are of this type, being devoid of dendrites. The single process which divides into two branches (central and peripheral) is considered to be an axon. The peripheral branch has the structure of a typical axon and, while usually conducting impulses toward the cell body, can conduct in the reverse direction (*antidromic conduction*).

Bipolar neurons have two processes: a single axon and a single dendrite. A cell body is usually fusiform in shape, with processes arising from opposite ends of the cell. These neurons are found in the retina, in certain ganglia (vestibular and cochlear), and in the olfactory epithelium.

Multipolar neurons have a single axon and a variable number of dendrites (for example, the motor neurons in the gray matter of the spinal cord).

2. *On the Basis of Function.* Neurons are afferent, efferent, or internuncial.

Afferent or sensory neurons carry sensory impulses from the periphery. They are mostly pseudo-unipolar, having globular cell bodies located in the dorsal root ganglia of spinal nerves or on the sensory roots of cranial nerves. Each possesses a single T-shaped process which divides into a *central branch*, terminating in the spinal cord or the brain, and a *peripheral branch* which terminates in sensory receptors in the body wall or viscera. Some sensory neurons are bipolar.

Efferent neurons carry motor impulses from the central nervous system or from ganglia to effector organs or structures, which respond. Depending on the nature of the effect and the response produced, efferent neurons are either (1) *motor neurons*, whose axons end in voluntary muscles which contract when stimulated; (2) *secretory neurons*, whose axons end in glands which secrete when stimulated; (3) *accelerator neurons*, whose axons end in visceral or cardiac muscles, either initiating or speeding up their activity; or (4) *inhibitory neurons*, whose axons end in visceral or cardiac muscle, either retarding or stopping their activity.

Internuncial (or *association*) neurons lie within the central nervous system. They conduct impulses from one neuron to another.

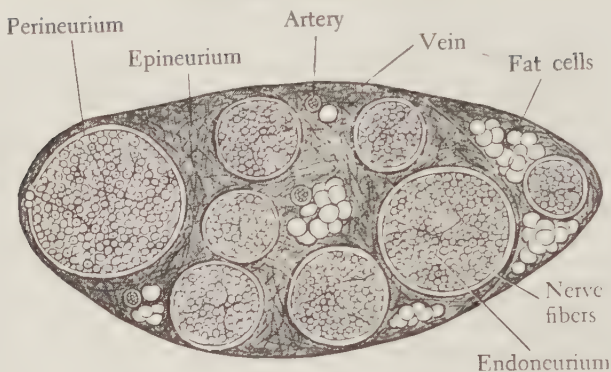


Fig. 3-2. Cross section of a nerve. (Reprinted with permission of The Macmillan Company from Kimber et al., *A Textbook of Anatomy and Physiology*, 13th ed., 1955.)

Neuroglia. The term “neuroglia” is applied to cells comprising the interstitial tissue of the nervous system. They include *ependyma*, *neuroglia proper* (“glia cells”), *satellite* or *capsular cells*, and *neurilemma* (and Schwann cells).

EPENDYMA. Ependymal cells line the ventricles of the brain and the central canal of the spinal cord.

NEUROGLIA PROPER. Glia cells are present in the brain and the spinal cord, lying between the neurons. There are three types of glia cells:

1. *Astrocytes* have numerous processes, some with expanded ends which may be attached to blood vessels.
2. *Oligodendrocytes* are similar to astrocytes, but their processes are fewer and thinner and lack expanded endings.
3. *Microglia* are small, many-branched cells with processes bearing numerous tiny points or spines.

Astrocytes and oligodendrocytes, like neurons, are ectodermal in origin. Microglia are thought to be mesodermal in origin, making their way to the central nervous system by way of blood vessels.

Neuroglia cells serve to support neurons and probably play an important role in their normal metabolism. They are active in pathological processes. Some, especially the microglia, may become actively amoeboid and phagocytic; they are involved in degenerative and regenerative processes following injury, and are the principal cells involved in the formation of brain tumors.

SATELLITE OR CAPSULAR CELLS. These small cells surround the cell bodies of sensory neurons in peripheral ganglia.

NEURILEMMA. Cells of Schwann lie underneath the neurilemma, surrounding the peripheral processes of cranial and spinal nerves.

Nerves. Nerves are glistening white structures lying outside the central nervous system, through which impulses are conducted. A nerve is made up of nerve fibers (axons and dendrites) and their coverings. The fibers may be medullated or nonmedullated. The fibers comprising a nerve are grouped together into bundles called *fasciculi* (or *funiculi*). Each fasciculus is encased in a thin covering of connective tissue known as *perineurium*, from which thin strands of connective tissue extend inward among the nerve fibers, constituting the *endoneurium*. The fasciculi, in turn, are enclosed by a layer of connective tissue composed mainly of collagenous fibers, forming the *epineurium*. The epineurium comprises the membranous covering of the nerve; it contains blood vessels and, usually, some adipose tissue. The epineurium is also supplied with sensory nerve fibers, the *nervi nervorum*.

Nerves and nerve trunks vary greatly in size. Near the brain and spinal cord, they contain many fibers and are relatively large. Distally, they divide and subdivide until at the periphery they may be extremely small.

Within a nerve, nerve fibers may pass from one bundle to another, or they may split into branches which join the branches of other nerves, forming an anastomosing network called a *nerve plexus*. This property is especially pronounced in the nerves that supply the extremities.

Tracts. In the brain and the spinal cord, nerve fibers are grouped into functional pathways called *tracts*. In the brain, these tracts serve to connect one part with another or to conduct impulses to or from the spinal cord. In the cord, certain tracts (*ascending tracts*) carry afferent impulses to the brain; others (*descending tracts*) carry efferent impulses from the brain.

Nerve tracts in the brain contain three types of fibers:

1. *Projection fibers* connect the cerebral cortex with the brain stem or the spinal cord.
2. *Commissural fibers* connect one side of the brain with the other.
3. *Association fibers* connect different parts of the brain on the same side.

The *cell bodies* of the fibers forming these tracts lie in the gray matter of the brain and the spinal cord.

Gray Matter and White Matter. In the brain and spinal cord, two kinds of matter can be distinguished grossly by their color, namely, the gray matter and the white matter.

GRAY MATTER. This consists principally of cell bodies and their dendrites, nonmyelinated nerve fibers, and the supporting neuroglia elements. It is found in the cortex, the basal ganglia, and the nuclei of the brain; in the gray columns of the spinal cord; in peripheral ganglia; and in the retina of the eye.

Gray matter constitutes the nerve centers where impulses are re-

ceived, connections made, and impulses discharged back to effector organs. Its primary functions are *integration*, *correlation*, and *coordination* of body activities. It provides the physical basis for the accomplishment of higher nervous functions, such as perception, thinking, judgment, and emotion.

WHITE MATTER. This is composed principally of myelinated nerve fibers and their supporting neuroglia cells. It is found in the commissures and tracts of the brain and in the fiber tracts of the spinal cord. It contains few, if any, nerve cell bodies.

In general, the white matter serves to carry impulses from the peripheral portions of the body to and from the central nervous system or between various parts of the brain and the spinal cord. Its primary function is *conduction*.

Ganglion. A ganglion is an aggregation of nerve cell bodies and the proximal portions of their processes, together with their supporting glia cells.

Important ganglia are the *basal ganglia* of the brain, the *spinal ganglia* on the posterior roots of spinal nerves, and the *autonomic ganglia*. Ganglia are usually found outside the central nervous system.

Nucleus. A nucleus is a localized mass of nerve cell bodies in the brain or the spinal cord whose axons form certain nerves, fasciculi, tracts, or commissures. Nuclei are of two types: *nuclei of origin* and *nuclei of termination*.

NUCLEI OF ORIGIN. These are accumulations of cell bodies whose axons form a nerve root or fiber tract. An example is the dorsal motor nucleus of the vagus nerve, located in the medulla.

NUCLEI OF TERMINATION. These are accumulations of cell bodies in which the axons of a nerve or fiber tract terminate. Through synapses the cell bodies receive impulses from terminating axons of afferent neurons. An example is the nucleus cuneatus in the medulla, which receives and relays sensory impulses of touch.

Peripheral Nerve Endings. All the fibers in peripheral nerves, whether motor, sensory, secretory, or inhibitory, terminate in some peripheral organ or structure. The fiber may terminate singly or it may branch repeatedly, forming *terminal arborizations*. It may end as a *free or naked nerve ending*, or in a specialized structure.

Depending on their particular functions, peripheral nerve endings may be designated as either receptors or effectors.

RECEPTORS. Receptors are nerve endings or specialized sensory cells which respond to stimuli. They are of three types: exteroceptors, interoceptors, and proprioceptors.

Exteroceptors. Exteroceptors are stimulated by changes in the external environment. They are located on or near the surface of the body. They are either *general somatic* receptors or *special somatic* re-

ceptors. General somatic receptors include the widely distributed end organs of touch, pressure, heat, cold, and pain. Special somatic receptors include the auditory organ in the cochlea of the ear, the organs of equilibrium in the vestibule and semicircular canals of the ear, and the visual organ or retina.

Interoceptors. Interoceptors are stimulated by changes in the internal environment. They are located in the viscera or internal organs. *General visceral* receptors are free nerve endings giving rise to sensations, such as pain, hunger, thirst, fatigue, nausea, and suffocation. *Special visceral* receptors include the olfactory cells of the nasal epithelium and gustatory cells in taste buds.

Proprioceptors. Proprioceptors are stimulated by changes in position of body parts. They are located in muscles, tendons, and joints. They include neuromuscular and neurotendinous spindles.

The term "receptor" has several meanings as used by various authors. It has been applied to: (1) a sensory nerve ending; (2) a specialized receptor cell, such as an olfactory or gustatory cell or a pain receptor; (3) an entire sense organ, such as the eye or ear; (4) an entire sensory neuron, as in a reflex arc. In this volume, the first two meanings are applied.

EFFECTORS. Effectors are the terminal portions of efferent neurons which transmit impulses to an effector organ, such as a muscle or a gland. They may be naked nerve endings or motor end-plates (myoneural junctions).

Naked Nerve Endings. These terminate in smooth or cardiac muscles or in glands. Their nerve fibers may have slight terminal enlargements. The fibers come into close contact with the cells, but apparently they do not actually penetrate the protoplasm.

Motor End-plate or Myoneural Junction. This kind of structure is found at the junction between the axons of motor neurons and the fibers of striated muscles. It consists of a mass of muscle sarcoplasm lying just beneath the sarcolemma in which the naked axis cylinder (axon) ends. A number of muscle nuclei may be grouped about the plate. The portion of the plate in contact with the contractile substance of the fiber is called the *sole*.

The term "effector" has several meanings as used by various authors. It has been applied to: (1) the terminal portion of the axis cylinder of an efferent neuron; (2) an entire efferent neuron, as in a reflex arc; (3) an organ in which a response is elicited, as a muscle or a gland. In this volume, only the first meaning applies.

Nerve Degeneration and Regeneration. It is generally believed that after neurons become differentiated in embryonic development they lose their power of multiplication. According to this, after birth the nerve cells cannot be replaced if destroyed. (The latter statement ap-

plies only to neurons in their entirety; under certain conditions, the processes of neurons may be regenerated if the cell body remains intact.)

Neurons in the central nervous system may die as the result of injury, infections, irradiation, poisoning, or senility. When this occurs, loss of function may ensue. In some instances, however, other neurons apparently have the capacity for taking over the function that was performed by the destroyed neurons.

WALLERIAN DEGENERATION. Outside the central nervous system, when a nerve is cut or injured, fibers in the distal portion of the nerve undergo degeneration. This is especially true of the axons. *Degeneration* begins at the point of injury and progresses distally. The axon becomes tortuous and fragmented, then disappears. The myelin sheath breaks down and the fat accumulates in the form of globules. For a period of several weeks, it can be stained by the Marchi method. The neurilemma persists, but in a somewhat altered condition. Because of its altered staining properties, the degenerated myelin can be traced easily; hence the course of nerve fibers undergoing Wallerian degeneration can be readily followed. Degeneration of this type is usually completed in two or three weeks, after which the degenerating myelin is resorbed.

Regeneration occurs through the growing out of a new axis cylinder from the central portion of the injured fiber. New fibrillae tend to follow the course of the old neurilemma (and Schwann cells), which meanwhile has become somewhat like connective tissue cells. Growth of the regenerating fiber is slow, requiring weeks or months to re-establish former connections. If the two ends of a severed nerve are brought close to each other, the process occurs much more rapidly than if they remain separated; in the latter case, regeneration may not occur at all. Since new fibers follow the course of the old neurilemma, it is thought that the presence of neurilemma is essential for the regeneration of nerve fibers. Furthermore, regeneration does not occur in the central nervous system, where the neurons lack a neurilemma.

RETROGRADE DEGENERATION. This term is applied to changes that occur in the cell body and in the proximal portions of an axon which has been cut or injured. When retrograde degeneration takes place, the Nissl bodies disintegrate and the chromophil substance becomes scattered in the form of granules through the cytoplasm. Changes may also occur in the nucleus, and the water content of the cell may increase, with swelling and vacuolization. This process is called *chromotolysis*. Usually the cell dies, but it may recover.

TRANSYNSYNAPTIC DEGENERATION. Although, in the case of injury to neurons, degenerative processes take place only in the injured neuron,

neurons having synaptic connections with the injured cell may be affected. This synaptic degeneration is encountered commonly in the optic tract of the brain.

THE NEURON THEORY—THE SYNAPSE

Formulated by Heinrich Wilhelm von Waldeyer in 1891, the neuron theory postulates that the nervous system is made up of neurons; and that a neuron, with its processes (dendrites and axon) is the cytological and trophic unit of the nervous system. According to this theory, all parts of the body are connected by complex series of neurons which carry impulses to and from the various parts. Impulses pass through the dendrites of a single neuron to its cell body, then from the cell body out through the axon, which makes connections with the dendrites or the cell body of another neuron or neurons, these in turn conducting the impulse to still other neurons or effector organs. The point of contact of one neuron with another is called the *synapse*, and the cell membranes of the two neurons at this synapse constitute the *synaptic membrane*.

Characteristics of Synapses. Synapses are characterized by (1) a state of polarity, (2) resistance, and (3) susceptibility to fatigue.

POLARITY. A state of polarity exists at the synapse whereby impulses pass in only one direction, namely, from the axon of one neuron to the dendrites or cell body of another; impulses *never* pass in the reverse direction.

RESISTANCE. Synapses offer a certain resistance to the passage of an impulse. This can be determined by comparing the time required for passage of an impulse through a reflex arc, which involves synaptic conduction, with the conduction time through the fiber of a single neuron. This fact is of importance to the understanding of habit formation. Certain pathways are established even at the time of birth; they account for the actions by which a new-born child carries out functional activities or responds to stimuli. In learned actions, however, new pathways for the transmission of impulses must be established. For the simpler actions, this is easily accomplished; once an impulse follows a certain pathway, succeeding impulses aroused by the same or similar stimuli tend to follow the same course. It is assumed that the explanation for this lies in the lowering of synaptic resistance. It should be noted, in this regard, that when synaptic resistance is abnormally low, useless and uncontrolled activity results, as in the "highly nervous" person. Such an individual may respond actively to weak stimuli; for example, he may jump at the slightest sound.

SUSCEPTIBILITY TO FATIGUE. Synapses are subject to fatigue; that is, their capacity to transmit impulses becomes reduced following continued activity. To illustrate, when a muscle is made repeatedly to

contract through stimulation of a given receptor, fatigue ensues. However, should the stimulus be applied to another receptor whose impulses follow the common pathway, the muscle will contract with its original vigor. Since the muscle apparently is not fatigued and nerve fibers do not exhibit fatigue except following very prolonged activity, the site of the fatigue is probably in the synapse.

Types of Synaptic Connections. Synapses are either *axosomatic* (in which axon telodendria of one neuron make contact with the cell body of another) or *axodendritic* (in which axon telodendria of one neuron make contact with the dendrites of another). There are four kinds of structures which serve to make this contact with the adjoining neuron:

1. *Terminal bulbs* (boutons terminaux or neuropodia), bulb-like expansions at the ends of axons which come into contact with cell bodies.

2. *Pericellular networks*, terminal fibers of an axon which form a net covering the surface of a cell body.

3. *Terminal tufts*, terminal fibers of an axon which intermingle with branches of dendrites of an adjoining neuron, forming a tuft-like structure.

4. *Parallel axodendritic fibers*, terminal fibers of an axon which are parallel to, and lie in apposition with, branches of dendrites of an adjoining neuron.

Two facts are apparent from the structure of synapses: (*a*) that one neuron may receive impulses from the axons of several other neurons, and (*b*) that one neuron, through its axon, may transmit impulses to several other neurons.

Evidence in Support of the Neuron Theory. The evidence that supports the neuron theory is derived from what is known of the structure and development of neurons, from the inability of histologists to demonstrate actual connections between adjoining neurons, and from the fact that when degenerative changes occur in a neuron such changes do not spread, except in rare cases, across the synapse to adjoining neurons. In recent years the neuron theory has been seriously questioned, but to date the theory explains better than any other the functioning of the nervous system.

GENERAL PHYSIOLOGY OF THE NERVOUS SYSTEM

The general physiology of the nervous system depends upon certain fundamental properties of the system, the nature of nerve impulses, and the action of stimuli.

Fundamental Properties of the Nervous System. Two fundamental properties possessed by protoplasm are developed to a high degree in nerve cells. They are irritability and conductivity.

IRRITABILITY. The capacity of protoplasm to respond to a stimulus is called *irritability*. This property is especially well developed in the endings of afferent nerve fibers and in special receptor cells which are capable of responding to environmental changes. Indeed, a *stimulus* may be defined as an environmental change capable of initiating activity within the protoplasm of a cell.

CONDUCTIVITY. Following stimulation, a wave of irritability, or protoplasmic change, sweeps through the entire cell and its cell processes (axon, dendrites). This property is referred to as *conductivity*. The wave of irritability is the *nerve impulse*. Upon reaching the end of a nerve fiber, the impulse is capable of initiating, through a synapse, an impulse in the adjoining neuron; or it can bring about a response in an effector organ, such as a gland or a muscle.

Nerve Impulses. As far as can be determined, all nerve impulses are alike, irrespective of the nature of the stimulus that induces them, the type of neuron over which they pass, or the type of sense organ in which they originate. Sensory and motor impulses are identical in nature. The variety of sensations produced by different stimuli and the variety of responses are accounted for principally by the differences in the nature of the receptor and effector organs.

THEORY OF IMPULSE CONDUCTION. There are several theories of nerve impulse conduction, but the "membrane theory" is the most generally accepted. In brief, this theory accounts for impulse conduction as follows:

1. The resting nerve fiber is a polarized structure bearing positive ions on the outer surface of its membrane and negative ions on its inner surface. The membrane is semipermeable.

2. A stimulus increases the permeability of the membrane, permitting the union of positive and negative charges (depolarization).

3. Depolarization acts as an action potential, which serves as a stimulus to the next adjacent portion of the fiber, and this, in turn, becomes depolarized.

4. The change thus propagated passes along the nerve fiber; this is the nerve impulse.

5. Immediately after passage of an impulse, that portion of the fiber is *refractory*; that is, it is unable to conduct another impulse. This refractory period lasts for only a very short interval, 0.001 to 0.005 second), during which time the cell membrane is restored and polarization of the fiber is re-established, whereupon the fiber is capable of conducting another impulse.

THE CHANGES THAT ACCOMPANY NERVE IMPULSE CONDUCTION. A nerve impulse involves thermal, chemical, and electrical changes.

Thermal Changes. Some heat is produced, but the amount is so minute that instruments of the most delicate kind are required for its

detection. The heat appears to be produced through oxidative processes involved in recovery of irritability.

Chemical Changes. A minute quantity of oxygen is consumed, and carbon dioxide is liberated. There are also changes in amounts of phosphocreatine, glycogen, lactic acid, and ammonia.

Electrical Changes. When the electrodes of a capillary electrometer are placed on the uninjured surface of a resting nerve, it is noted that no current is indicated. That is to say, all points on that surface are isopotential (have the same degree of electrification). If the nerve is injured, however, and one electrode is placed on the injured portion and another on the uninjured portion, the electrometer will reveal the presence of a current. The point of injury is electrically negative, the uninjured portion electrically positive.

If one stimulates a nerve to which electrodes have been attached, and an impulse is initiated, an *action current* moves along the nerve fiber; the fiber at this point is always negative to the inactive part. The action current and the nerve impulse are always associated with one another, and for practical purposes they are identical.

CHARACTERISTICS OF NERVE IMPULSES. In order to understand fully the functioning of the nervous system, one must consider several characteristics of a nerve impulse. They are: (1) the all-or-none law, (2) direction of impulse movement, (3) nerve fatigue, (4) velocity of impulses, and (5) the blocking of nerve impulses.

The All-or-None Law. When a nerve fiber is stimulated, it conducts to its fullest extent regardless of the strength of the stimulus, provided that the stimulus is strong enough to initiate nerve activity. The law applies to any fiber individually. However, all impulses are not of the same magnitude, for altered conditions within a fiber, such as those brought about by subjecting the fiber to a narcotic (alcohol, for example), may alter its capacity for conductivity.

Although an individual fiber acts on the all-or-none principle, a nerve that is made up of several fibers does not. This accounts for graded responses, some weak and others strong, depending on the strength of the stimulus; a weak stimulus may stimulate only a few fibers, each conducting to its fullest extent, while a strong stimulus may stimulate many fibers.

Direction of Impulse Movement. A nerve fiber may conduct impulses in one of two directions: toward or away from the cell body. Normally, the conduction is *toward* the cell body in dendrites, *away* from the cell body in axons. At a synapse, however, impulses can pass in only one direction, namely, from the axon of one neuron to the dendrites or to the cell body of another.

Nerve Fatigue. From a practical standpoint, a nerve fiber does not become fatigued. Impulses can be made to pass through one indefi-

nitely without reducing the fiber's capacity to conduct additional impulses. However, abnormal conditions, such as oxygen deprivation, or effects of toxins or anesthetics, may diminish the excitability of nerve fibers and impair their ability to conduct impulses.

Velocity of Nerve Impulses. The velocity of a nerve impulse depends on a number of factors. Among these are:

1. *Temperature of the body.* Velocity is greater in warm-blooded animals than in cold-blooded animals.

2. *Size of nerve fiber.* Velocity is greater in nerve fibers of large diameter than in those of small diameter.

3. *Presence of myelin sheath.* Velocity is more rapid in myelinated fibers.

CHARACTERISTIC RATES OF IMPULSE CONDUCTION

| | <i>ft. per sec.</i> |
|---------------------------------------|---------------------|
| In large fibers of the sciatic nerve: | |
| in frog | 100-150 |
| in man | 280-300 |
| In thin, nonmyelinated fibers: | |
| in frog | 50 |
| in man | 3 |

The Blocking of Nerve Impulses. The process by which the passage of nerve impulses is stopped or obstructed is referred to as *blocking* or *deadening* a nerve. It can be accomplished as follows: (1) by cooling, (2) by application of pressure, (3) by application of electric current, and (4) with chemical substances.

1. *Cooling.* Nerve impulses can be obstructed by cooling to 0° Centigrade.

2. *Pressure.* Loss of sensation in a limb, as when the limb "goes to sleep," is due to pressure on the nerve. Removal of the pressure acts as a stimulus and gives rise to the "prickly" feelings, which are referred to the distal end of the extremity. Crushing of a nerve is another form of pressure. Crushing of a motor nerve results in temporary paralysis of the muscles. In one form of treatment of tuberculosis, the phrenic nerve is purposely crushed, resulting in cessation of movements of the diaphragm on the affected side.

3. *Electric current.* In certain circumstances, electric current is applied for the relief of pain from neuralgia or muscle cramps.

4. *Chemical substances.* The chemical substances which may be used to block nerve impulses are classified as anesthetics, sedatives, and hypnotics. Also included are analgesics, substances which relieve pain (analgesia being the absence of the normal sense of pain). Intoxication, a form of poisoning, also impairs the passage of nerve impulses.

Anesthesia is a state of partial or complete loss of sensation with or

without the loss of consciousness. In *local anesthesia*, sensation is lost in a limited area; substances such as cocaine, procaine, and novocaine, applied to specific nerves or nerve trunks, result in loss of sensation. In *regional anesthesia*, an extensive portion of the body, or a region, is involved; when the anesthetic is injected into the membranes of the spinal cord (as in spinal block), sensation is lost in all structures innervated by nerves below the level of the injection. Injections in or around a ganglion block the nerve impulses from all structures supplied by the ganglion. In *general anesthesia*, the loss of sensation is complete and consciousness is lost; it is accomplished by the inhalation of such anesthetics as ether, chloroform, and nitrous oxide. The exact mode of action of anesthetics is not known, although it is suspected that the effects of fat-dissolving substances, such as ether and chloroform, are due to their effects on the lipid substances of cells, especially neurons. In this action, the permeability of the cell membranes is altered and interference with function ensues.

Sedatives are substances which reduce nerve irritability and thus have a quieting effect. Some are general in their effects; others, such as cardiac, respiratory, gastric, and intestinal sedatives, are specific. Examples are certain bromides, chloral hydrate, pilocarpine, belladonna, and opium.

Hypnotics induce sleep or dull the senses. Aspirin and certain bromides are mild hypnotics. Stronger hypnotics include trianol, veronal, sulfonal, chloral and chloralamide, luminal (phenobarbital), and opium and its derivatives (morphine is one of them). Strong hypnotics (*narcotics*) may induce profound sleep or stupor.

Stimuli. A stimulus is an environmental change (external or internal) which excites living matter or initiates a nerve impulse.

TYPES OF STIMULI. Stimuli may be either physical (mechanical), chemical, thermal, or electric.

Physical (Mechanical) Stimuli. Physical stimuli are usually pressure changes. Examples are: contact with or penetration of the skin, distension of the intestine by gas, striking of air waves against the tympanic membrane, and stimulation of afferent nerve endings in the aortic arch or the carotid sinus by blood pressure.

Chemical Stimuli. Some of the substances which serve as stimuli are: acids or alkalies which come into contact with the skin or with mucous membranes, salt which makes contact with naked nerve endings, volatile gases which stimulate the olfactory cells, food substances which stimulate taste buds, and substances in the blood (such as CO_2 or hydrogen ions, which stimulate afferent nerve endings in the aortic arch and carotid sinus).

Thermal Stimuli. Temperature changes of the air can stimulate afferent fibers of the skin.

Electric Stimuli. Nerve impulses can be initiated by the flow or cessation of flow of electrons, as from a battery, an induction coil, or a generator.

CHARACTERISTICS OF A STIMULUS. In order to act effectively as a stimulus, an environmental change must possess the following characteristics: (1) It must *have a certain strength or intensity*. A stimulus which barely produces a sensation or response is called a *minimal* or *threshold stimulus* (also liminal stimulus or rheobase). (2) It must *act for a certain minimum length of time*. (3) It must *occur at a sufficiently rapid rate*.

THE REFLEX ARC—REFLEX ACTIONS

The reflex arc is the *functional unit of the nervous system*. It is a neuromuscular or neuroglandular mechanism through which most of the activities of the body are initiated.

A reflex arc consists of a series of neurons, over which impulses are conducted from a receptor or sense organ to the central nervous system (brain or spinal cord) and back to an effector organ, that is, a muscle or a gland. When a receptor is stimulated and a response, such as muscular contraction or glandular secretion, occurs, the action is called a *reflex action*.

A Simple Reflex Action. The simplest form of reflex arc involves only two neurons between receptor and effector organ. The structures involved in such a simple reflex are:

1. *A receptor*, comprising peripheral endings of afferent neurons.
2. *An afferent or sensory neuron*, which conducts impulses to the spinal cord. The impulse passes through the dendrite to the cell body, which lies in the spinal ganglion. The axon passes through the posterior root into the gray matter of the cord, where it synapses with a motor neuron.
3. *An efferent or motor neuron*, which has a cell body lying in the gray matter of the cord. The axon passes outward through the anterior root of a spinal nerve to its termination in an effector organ.
4. *An effector organ*, as, for example, a striated muscle.

Reflex actions can be readily demonstrated in an experimental animal such as the frog. Because the higher centers of the brain control voluntary movement, and consequently may tend to inhibit reflex activity, it is desirable to eliminate the possibility of such an influence. This can be achieved by (a) decapitating the animal; (b) destroying the brain by pithing (inserting a probe into the cranial cavity); or (c) severing the spinal cord in the cervical region. Such an animal is referred to as a "spinal animal," in which all activities are reflex actions. In some instances, only the cerebral hemispheres are destroyed, creating a "decerebrate animal."

If a "spinal" frog is suspended by the snout and a stimulus is applied (pinching the toe or applying a weak acid) to the skin of, say, the right leg, the stimulated leg will be withdrawn from the offending stimulus. If the stimulus is applied and the stimulated leg is restrained, after a short interval the other (or left) leg will be drawn upward, showing that the impulse has traveled to the opposite side of the cord. If a stronger stimulus is applied, both legs will be withdrawn, and if both legs are held so as to prevent contraction, a response will be noted in the muscles of the upper limbs. If a strong stimulus is applied to, say, the ventral region of the body, all four legs will contract. The last two illustrations indicate that the impulses travel *up and down* the cord.

In a spinal animal, reflex actions may be abolished by (a) cutting the nerves between the point of stimulation and the spinal cord, or (b) destroying the spinal cord by inserting a probe into the vertebral canal.

In the foregoing examples, at least three neurons were involved. These are:

1. *An afferent or sensory neuron.* This neuron is similar to that of the simple reflex arc, except that on entering the spinal cord, the axon synapses with an intermediate or internuncial neuron.

2. *Internuncial (associating or connecting) neurons.* These neurons lie in the gray matter of the cord. Their axons synapse with motor neurons in the same or opposite side of the cord.

3. *An efferent or motor neuron.* The cell body in this neuron lies in the ventral horn of the gray matter of the cord. The axon passes out through the anterior root of a spinal nerve to the effector organ, a striated muscle.

Reflex arcs involving glands, or smooth or cardiac muscle, utilize neurons of the autonomic nervous system. Such reflex actions are more complex because at least two neurons are involved in the efferent pathway: one whose cell body lies within the central nervous system, the other whose cell body lies in an autonomic ganglion.

Complex Reflex Actions. Reflex actions may be of relatively simple nature (such as the blinking of an eyelid), or they may be more complex (coughing or vomiting), or they may be extremely complex (such as the multiple responses involved in jumping from the path of an approaching automobile in response to the sounding of its horn).

CHARACTERISTICS OF REFLEX ACTIONS. The following characteristics apply to reflex actions in general.

1. *Reflex actions are involuntary.* The individual may or may not be conscious of the reflex act; in most cases, awareness of the act is nothing more than recognition by the brain that the reflex action has occurred.

2. *Reflex actions are purposeful and adaptive.* In the majority of instances, they are actions which are essential for the protection and general well-being of the body. Most of the activities concerned with locomotion, posture, and the movements of individual parts are reflexly controlled; the activities of the internal organs are primarily under reflex control.

3. *Reflexes are specific and predictable.* When a given stimulus brings about a specific reaction, it can be predicted with a high degree of reliability that repetition of the stimulus will evoke the same reaction.

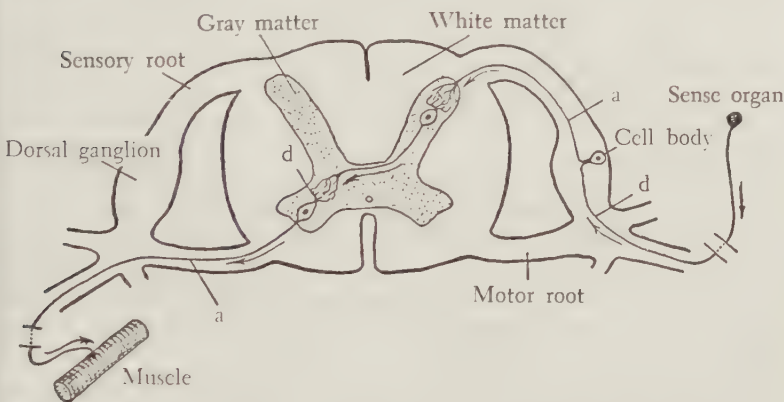


Fig. 3 3. Diagram illustrating relations between spinal cord and spinal nerves. Three neurons, constituting a simple reflex arc, are represented. The direction of the nerve impulse through these neurons is indicated by arrows. Abbreviations: a, axon; d, dendron. (From Alexander, *Biology*, College Outline Series, copyright, 1954, by Barnes & Noble, Inc.)

4. *Reflexes have a measurable reaction time.* In simple reflex actions, the response takes place much more quickly than in more complex reactions. Nevertheless, they do not occur instantaneously, for a measurable time always elapses between the application of the stimulus and the occurrence of the response. This time is called the reflex time, or *reaction time*. Reaction time is variable, depending on a number of factors; the principal of these are: (a) strength of the stimulus (in general, the stronger the stimulus, the shorter the reaction time); (b) complexity of the reaction (the more complex the activity, the longer the reaction time, because of the greater number of synapses involved); (c) the fundamental nature of the central nervous system (individual differences among organisms result in more rapid responses in some individuals than in others); and (d) prevailing physiologic condition of the central nervous system (for example,

fatigue or indulgence in alcohol; the time required for reflex actions is significantly increased under these and other conditions which impair the functioning of the nervous system).

SOME SPECIAL PHENOMENA RELATING TO REFLEX ACTIONS. Even simple reflex actions are not without their complicating influences. Such phenomena are inhibition, irradiation, facilitation, and summation, as well as the abnormal actions seen in convulsive reflexes.

Inhibition of Reflexes. A stimulus which reflexly induces the contraction of certain muscles may at the same time inhibit the contraction of other muscles. For example, in the patellar reflex, the extensor muscles contract and extend the leg. But in order that this may happen, the flexor muscles, which act antagonistically, must relax; that is, they must be inhibited from contracting. This inhibition of a reflex action is called the *law of reciprocal innervation*. Coordinated muscle activity would not be possible without a mechanism operating on such a principle.

In certain complex activities, a stimulus may cause the contraction of muscles on one side of the body and inhibit their contraction on the other side. For example, when one steps on a sharp object with the left foot, the flexor muscles of the left thigh contract, and this is accompanied by inhibition of the opposing extensors; at the same time, however, the extensors of the right thigh contract, and the opposing flexors of this side are inhibited.

At a much higher level of the nervous system, reflexes may be inhibited voluntarily, as in an effort to restrain coughing or crying. The prick of a sharp object normally elicits a cry of pain and movement away from the offending stimulus, but, if the stimulus occurs under conditions of strong social pressure (as in a church or a public library), the normal response will probably be completely suppressed or greatly reduced. Pressure on the upper lip will usually inhibit a sneeze, and pressure on the eyeball sometimes puts an end to hiccupping.

Irradiation. When a weak stimulus is applied, the impulses tend to leave the cord in the same segment in which they entered, producing a reaction on the same side of the body and usually near the point of stimulation. This is a *unilateral reflex*. A stronger stimulus may give rise to impulses which cross to the opposite side of the spinal cord, leaving the cord in efferent neurons of the same segment. This is a *bilateral reflex*. A still stronger stimulus may give rise to impulses which pass both up and down the spinal cord, to issue at points several segments above or below the point where the afferent impulses enter. This spreading of impulses throughout the central nervous system is known as *irradiation*, a phenomena which accounts for the increased responses resulting from increased stimulation.

Facilitation of Reflexes. Certain reflex actions can be amplified or

facilitated by bringing into play two or more stimulus-response mechanisms. In the knee-jerk (patellar) reflex, for example, if the leg is dangling loosely when the patellar tendon is struck, the leg will extend; but if the subject clinches his fist before the stimulus is applied, the amplitude of the response will be greatly increased.

Summation of Reflexes. A reflex action may be initiated by the stimulation of two different receptors. For instance, a bright light directed into the eyes may initiate a sneeze. Similarly, the cooling of the skin may produce the same effect. When either of these stimuli is inadequate to produce the response, both occurring together will usually bring about the reaction. Such an effect is called *spatial summation*. In some cases, a weak or subliminal stimulus is incapable of inducing a reflex response, but, if this stimulus is repeated several times, there is an addition or summation of effects which eventually brings about the response. This is called *temporal summation*.

Convulsive Reflexes. The law of reciprocal innervation is susceptible to several conditions which interfere with its operation. These conditions include strychnine poisoning and certain diseases. Strychnine is a marked stimulant of the central nervous system; when it has been administered in overdoses, a slight stimulus tends to produce exaggerated reactions, involving unrelated muscle groups. Coordinated excitation and inhibition are lacking. The result is paroxysms (also called "spasms" or "fits"), involuntary reflex contractions and relaxations, or *convulsions*. They may involve the entire body or be localized. Some of the abnormal conditions which may give rise to convulsions are: eclampsia, meningitis, uremia, dietary deficiencies, epilepsy, hysteria, heat cramps, and food poisoning.

CLASSIFICATION OF REFLEX ACTIONS. Reflex actions are either in-born (inherited) or conditioned (learned).

Inborn (Inherited) Reflexes. These include the fundamental reflex activities that are concerned with food-getting, self-protection, sound production, mastication, swallowing, defecation, micturition, and reproduction. Regulation and control of the visceral organs are maintained through reflex actions.

Conditioned (Acquired) Reflexes. Responses which occur as the result of training may or may not be directly related to the stimulus. For example, if food is placed before a hungry dog, the animal's salivary glands are reflexly stimulated and they begin to secrete saliva. Early in training, the sound of a bell will not bring about this secretion. However, if a bell is sounded on numerous occasions when the food is presented to the dog, the sound begins to be associated with the presence of the food, and eventually the sounding of the bell even in the absence of food will induce the secretion of saliva.

Many learned actions involve the establishment of conditioned re-

flexes. Indeed, many habits and a large part of the individual's behavior are the results of conditioned reflexes.

Specific Reflex Actions. The failure of a normal reflex action to take place is usually associated with a disturbance in the reflex pathway. If the afferent and efferent pathways are found to be intact, then the lesion must exist in a reflex center (the spinal cord or the brain). A knowledge of specific reflexes such as the following is therefore of value in diagnosing disorders of the central nervous system.

SPECIFIC REFLEXES

| <i>S—Stimulus</i> <i>Proprioceptive</i> | <i>R—Response</i> <i>Exteroceptive</i> |
|--|---|
| Knee Jerk (Patellar) Reflex | Corneal Reflex |
| S—Tapping patellar tendon | S—Touching cornea |
| R—Extension of leg | R—Closing of eyelid |
| Flexor Reflex | Pupillary Reflex |
| S—Pinching foot, or pricking foot with a pin | S—Light striking retina |
| R—Flexion of thigh, withdrawal of foot | R—Constriction of pupil |
| Achilles Reflex | Ciliospinal Reflex |
| S—Tapping tendon of Achilles | S—Pinching nape of neck |
| R—Extension of foot | R—Dilation of pupil |
| Chin Jerk Reflex | |
| S—Tapping or suddenly depressing lower jaw while it is half open | |
| R—Sudden closing of jaw | |
| Cremasteric Reflex | |
| S—Stroking skin on inner side of thigh | |
| R—Elevation of testes | |
| Plantar Reflex | |
| S—Stroking sole of foot | |
| R—Plantar flexion of toes * | |
| Abdominal Reflex | |
| S—Stroking skin of abdomen | |
| R—Contraction of abdominal muscles | |

* In infants, and sometimes in adults, during sleep dorsiflexion or extension of the toes (Babinski's sign) may occur. While it is regarded as normal in children, this response in adults indicates disease of the corticospinal tracts.

Reflex Centers. Reflex centers are areas in the spinal cord or the brain where connections are made between the afferent neurons and efferent neurons of a reflex arc. Examples of reflex actions that involve various reflex centers are:

1. *Those involving centers in the spinal cord.* The examples related for "spinal" animals (page 73) illustrate this type.
2. *Those involving centers in the medulla oblongata.* In the medulla

oblongata are located several important centers through which body activities are regulated; among them are the vital cardiac, vasomotor, and respiratory centers, as well as those for swallowing, vomiting, coughing, sneezing, and winking.

3. *Those involving centers in the cerebellum and midbrain.* Although specific centers have not been identified in the cerebellum, all reflex activities associated with locomotion and maintenance of posture depend on impulses which pass through the cerebellum and, in some cases, the midbrain. In these areas, one finds the terminus of afferent fibers of the vestibular branch of the acoustic nerve, which plays an important role in postural reflexes.

4. *Reflexes involving centers in the diencephalon.* The hypothalamus contains reflex centers concerned with the regulation of body temperature. These centers regulate heat production reflexly by increasing the metabolic rate or the activity of striated muscles (shivering). Heat loss is reduced by constriction of peripheral vessels and erection of hairs ("goose pimples"); it is increased by vasodilation and secretion by the sweat glands.

5. *Reflexes involving centers in the cerebral hemispheres.* The cerebral cortex presents a wide range of possible connections between receptors and effector organs. Some of the reflex actions are relatively simple (e.g., the pupillary reflex). Others are complex (e.g., jumping and screaming upon viewing a frightening scene). In the latter, visual impulses, on reaching the visual centers, are relayed through association neurons to motor neurons which may bring about widespread responses throughout the body. All conditioned reflexes involve connections made in the cerebral cortex.

Summary of Reflex Actions. Some general principles concerning reflex actions should be borne in mind in study of the nervous system.

1. Reflexes may be simple or very complex. The simplest reflexes involve centers in the spinal cord only; the more complex have centers in the brain stem or cerebellum; the most complex, including conditioned reflexes, have their centers in the cerebral hemispheres.

2. Reflexes may involve any afferent neuron, any efferent neuron, or any other part of the central nervous system. They may bring about responses in striated, smooth, or cardiac muscle, or in glands.

3. A single stimulus may produce a very limited response, or it may bring into play many efferent neurons, producing widespread responses by the organism. Impulses may enter the central nervous system from several different receptors and be channeled through a common efferent pathway. This is called *convergence*. It may result in a limited response. Or impulses arising from stimulation of a single receptor may be channeled through many afferent pathways, resulting in numerous and widespread responses. This is known as *divergence*.

4: THE CENTRAL, PERIPHERAL, AND AUTONOMIC NERVOUS SYSTEMS

The nervous system has a structure which enables it to function as the master coordinating or integrating system of the body, maintaining the unity and harmony of the organism as a whole and adjusting its internal state to the environment within and the environment without. As described in the preceding chapter, the nervous system has two principal anatomic divisions: the central and the peripheral.

The *central nervous system* comprising the brain and the spinal cord, serves as a sort of switchboard receiving impulses from receptor organs and making connections by which the impulses are dispatched to effector organs, the responding mechanisms. It is the control center through which all body activities except those under chemical control are regulated.

The *peripheral nervous system*, comprising the cranial and spinal nerves and the sympathetic division of the autonomic nervous system, serves to connect peripheral organs with the central nervous system. Afferent nerve fibers conduct impulses centrally; efferent fibers conduct them peripherally.

The *autonomic nervous system* is a functional rather than an anatomic division. It includes nerves and ganglia which innervate all visceral organs and structures that function involuntarily.

EMBRYONIC DEVELOPMENT

An understanding of the early development of the nervous system is helpful in the study of neural structure and function.

Development of the Central Nervous System. The nervous system arises in the embryo from the surface layer, the *ectoderm*. Along the longitudinal axis in the middorsal region a thickening develops, forming a *neural plate*. As a result of unequal growth and folding, this plate gives rise to two longitudinal ridges, the *neural folds*, which enclose the *neural groove*. Along the margin of each fold lies a group of cells which forms the *neural crest*. The neural folds meet along the midline and fuse, forming a *neural tube*, which becomes detached from the ectoderm and comes to rest just beneath the surface layer of the embryo. The neural tube develops into the brain and spinal cord. The *neural canal* (the cavity within the tube) develops into the ventricles of the brain and the central canal of the spinal cord.

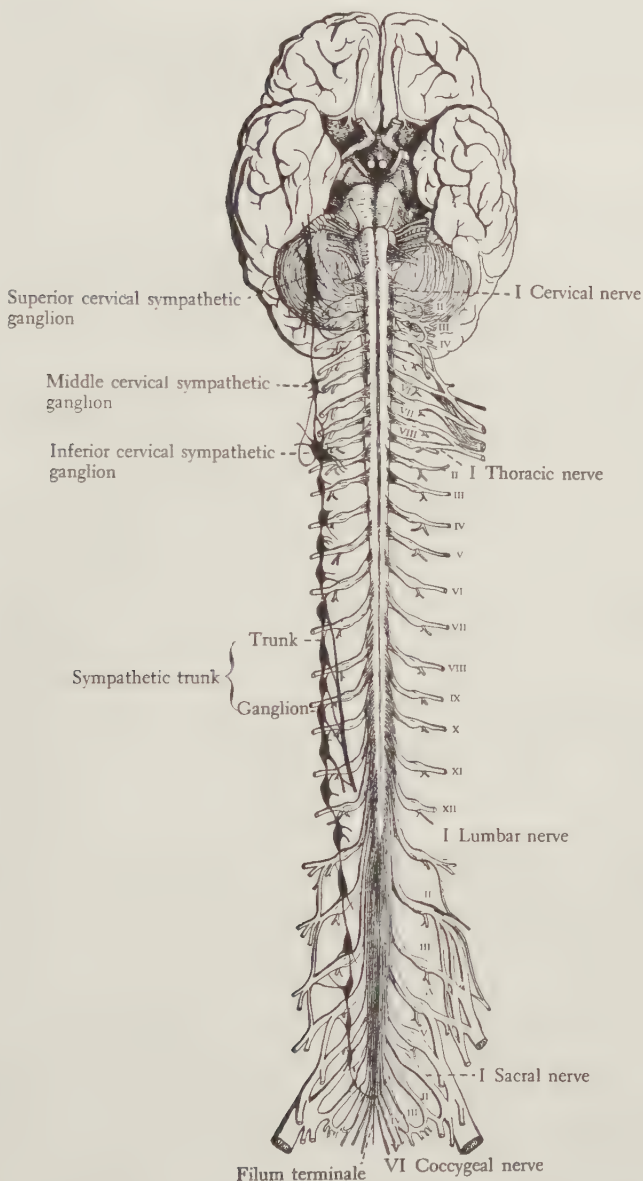


Fig. 4-1. Anterior view of central nervous system, with proximal portion of sympathetic nervous system. Brain straightened dorsalward with reference to spinal cord. (After Allen Thomson from Rauber, modified.) (Reprinted with permission of Blakiston Division, McGraw-Hill Book Company, from *Morris' Human Anatomy*, 11th ed., edited by J. P. Schaeffer, 1953.)

Growth in the anterior end of the neural tube is more rapid than in the remaining portion. Three regions are soon distinguishable from each other by slight constrictions; these are the *forebrain*, the *midbrain*, and the *hindbrain*, from which the various parts of the brain develop. The derivatives of each part are shown in the following table:

| <i>Primary Divisions</i> | <i>Subdivisions</i> | <i>Derivatives</i> | <i>Cavities*</i> |
|--------------------------------|---------------------|--|--|
| Prosencephalon (Forebrain) | Telencephalon | { Rhinencephalon Corpora striata Cerebral cortex | Lateral ventricles Rostral portion of third ventricle |
| | Diencephalon | { Epithalamus Thalamus Hypothalamus Optic chiasm Hypophysis Tuber cinereum Mammillary bodies | Most of the third ventricle |
| Mesencephalon (Midbrain) | Mesencephalon | { Corpora quadrigemina Tegmentum Crura cerebri | Cerebral aqueduct |
| Rhombencephalon (Hindbrain) | Metencephalon | { Cerebellum Pons | Fourth ventricle |
| | Myelencephalon | Medulla oblongata | |

* The cavities are described on pages 99–101.

Development of the Peripheral Nervous System. During the formation of the neural groove, a longitudinal ridge of cells forms on each side at the junction of the ectoderm and the tube; these are the *neural crests*, previously mentioned. After closure of the neural tube, the neural crests come to lie between the tube and the myotomes, and from these arise the cranial and spinal ganglia, as well as the autonomic ganglia. Ganglion cells in the spinal ganglia develop processes some of which grow centrally and penetrate the walls of the neural tube. These processes form the posterior roots of spinal nerves. Other processes of ganglion cells grow peripherally and unite with anterior root fibers, which grow outwardly from cell bodies located in the ventral portion of the tube. The union of these two groups of fibers results in the formation of a spinal nerve.

Sympathetic ganglia are formed by the migration of cells from the spinal ganglia and neural tube along the dorsal nerve roots and the nerve trunks to a position dorsal and lateral to the aorta, where they

become organized into vertebral ganglia arranged as a pair of sympathetic trunks. By a similar mechanism, the other ganglia (prevertebral and terminal) of the autonomic nervous system are formed.

THE BRAIN

The brain is that part of the central nervous system lying within the cranial cavity. For convenience it is divided into three regions: the brain stem, the cerebellum, and the cerebrum. The *brain stem*, the most inferior region, comprises the medulla oblongata, pons, midbrain, and diencephalon. The *cerebellum* lies posterior and superior to the brain stem. The *cerebrum* is a greatly expanded portion, lying superior to and almost completely covering the brain stem and cerebellum.

General Functions of the Brain. In general, the brain serves as:

1. *A regulatory center.* Through the activity of the brain, body activities are integrated, regulated, and controlled. Sensory impulses are received, and motor or inhibitory impulses are discharged to muscles or glands, whereby adjustments are made to the changing internal or external environmental conditions.

2. *The seat of consciousness.* The brain is the center of consciousness, which is the state of awareness of time, place, person, and, in greater or lesser degree, the activities of the body.

3. *The seat of sensations.* The brain interprets sensory impulses received from the various sense organs (for example, eyes, ears, nose, taste buds, skin, proprioceptors), giving rise to sensations (e.g., sight, hearing, smell, taste, touch, pain, and movement).

4. *The sources of voluntary acts.* All voluntary acts are initiated by the brain.

5. *The seat of emotions.* The feelings, drives, or urges which profoundly affect behavior are dependent on brain activity.

6. *The seat of higher mental processes.* Thought, reasoning, judgment, memory, and learning are possible only through activity of the brain.

Anatomy and Physiology of the Brain. Following are descriptions of the structure and functions of the parts of the brain. (The coverings of the brain, the meninges, are discussed on pages 97-99.)

MEDULLA OBLONGATA (SPINAL BULB). The medulla oblongata, the lowermost portion of the brain, lies between the pons above and the spinal cord below. It is directly continuous with the cord; there is no line of demarcation between it and the cord since nerve tracts and fibers continue through the foramen magnum without interruption from medulla to cord.

Structure of the Medulla Oblongata. The medulla oblongata is roughly triangular in shape, and measures about 3 cm. in length, 2 cm.

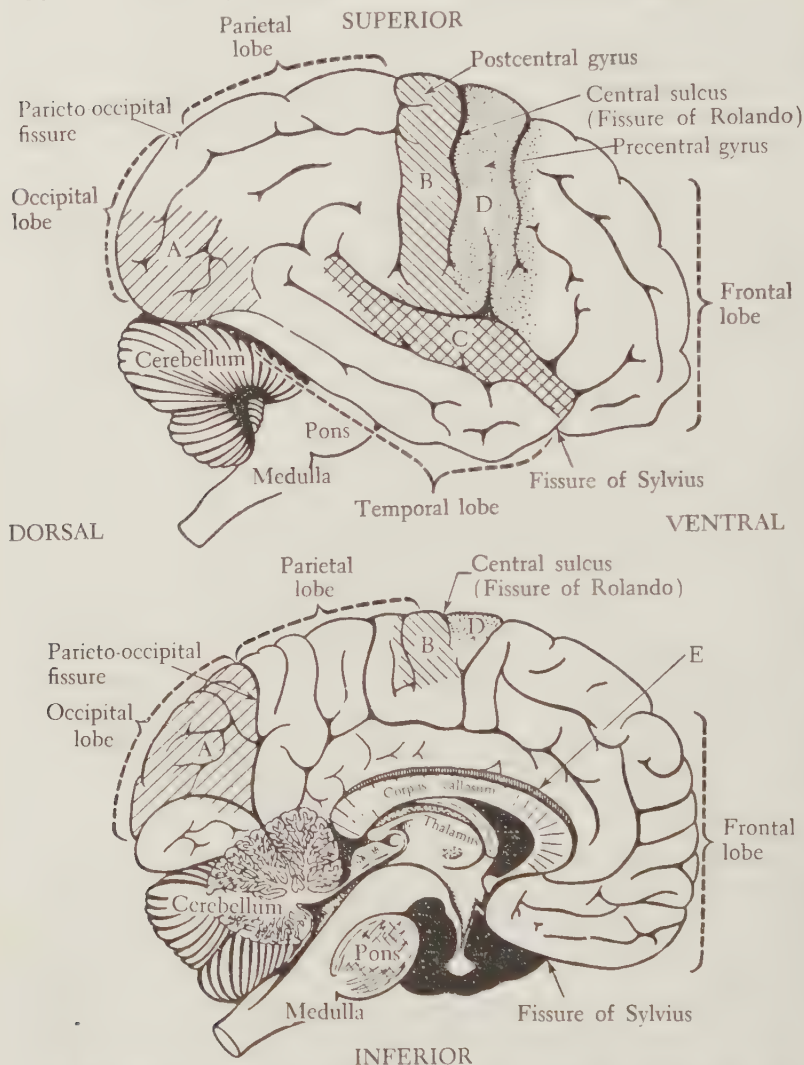


Fig. 42. The brain. Above: Lateral view of right cerebral hemisphere, showing schematically the important fissures, lobes, and projection centers of the cortex, the medulla and pons, and the cerebellum. The dotted area (D) represents roughly the origin of the main efferent tracts conducting impulses from the cortex to the lower coordination centers; and cross-hatched areas (A, B, and C) represent sensory areas for vision, somethesis, and audition, respectively. Unidentified parts are integration areas. Below: Mesial view of left cerebral hemisphere, showing structures of brain stem, cerebellum, and cerebral cortex. The thalamus, corpus callosum (composed of nerve fibers connecting the two hemispheres), and part of the projection area for olfaction and gustation (E) are visible. (From Fryer et al., *General Psychology*, College Outline Series, copyright, 1954, by Barnes & Noble, Inc.)

in width, and 1.5 cm. in thickness. On its dorsal surface, there is a depressed area, the *fourth ventricle*, which narrows inferiorly to become continuous with the central canal of the spinal cord. A *posterior median fissure* forms a narrow groove on the posterior surface; the *anterior median fissure* forms a similar groove on the anterior surface. The latter of these extends the entire length of the medulla, ending at the pons in a small triangular area, the *foramen cecum*.

Lying alongside the anterior fissure are two longitudinal folds or enlargements, the *pyramids*. These contain nerve fibers connecting the upper portions of the brain with the spinal cord. Near the caudal end of the medulla about two-thirds of these fibers cross the median fissure; that is, they decussate, forming the *pyramidal decussation*.

On each lateral surface, dorsal to the pyramid, there is a rounded mass, the *olive*. Each olive gives rise to a bundle of fibers which crosses the midline of the medulla and, together with fibers from the nucleus gracilis and nucleus cuneatus, forms the major portion of the inferior cerebral peduncle, which passes to the cerebellum. Two shallow grooves may also be seen, the *anterior* and *posterior lateral sulci*. Roots of various cranial nerves emerge from these sulci.

The arrangement of the *gray* and *white matter* in the medulla is considerably different from that in the spinal cord. In the cord, the gray matter occupies the central portion; in the medulla oblongata, the presence of the fourth ventricle in the central dorsal portion causes the gray matter to be so distributed that it occupies the floor and sides of the ventricle. The gray matter contains a number of *nuclear masses* separated by masses of fibers which form the white matter. These nuclear masses are the nuclei of origin of efferent fibers and nuclei of termination of afferent fibers. Among the important nuclei are the *nucleus gracilis* and the *nucleus cuneatus*, as well as various nuclei of the cranial nerves.

Superiorly, the medulla oblongata is connected dorsolaterally to the cerebellum by the *inferior cerebellar peduncles* or *restiform bodies*. It is separated from the pons by a furrow from which the abducens, facial, and acoustic nerves emerge.

Functions of the Medulla Oblongata. The medulla oblongata performs the following functions:

1. It contains the following nuclei: (a) the nuclei of termination of certain ascending tracts of the spinal cord; (b) the nuclei of termination of certain cranial nerves (V, VII, IX, X); and (c) the nuclei of origin of certain cranial nerves (IX, X, XI, XII).

2. It is the connecting pathway for ascending and descending fibers between the spinal cord and other portions of the brain.

3. It contains important reflex centers regulating certain vital activities, namely, the *cardiac center* (which regulates heart beat), the

respiratory center (which regulates the rate of respiration), and the *vasoconstrictor center* (which regulates the diameter of the blood vessels). There are other centers which mediate the swallowing and vomiting reflexes.

PONS (PONS VAROLII). The pons lies directly above the medulla and anterior to the cerebellum. It is somewhat ovoid in shape and presents on its ventral surface a transverse band of fibers arched like a bridge (hence the name, pons). These fibers converge on either side to form the middle *cerebellar peduncle* (*brachium pontis*), which connects the pons with the cerebellum. From the anterior surface of these peduncles emerge the roots of the trigeminal nerve (V); from the groove separating the pons from the medulla emerge the roots of cranial nerves VI (abducens), VII (facial), and VIII (acoustic).

Structure of the Pons. The pons has two regions: the basilar or ventral portion and the tegmental or dorsal portion.

The *basilar portion* consists of transverse fibers, longitudinal fibers, and pontine nuclei. The *transverse fibers*, lying in a thick layer on the ventral surface of the pons, together with some of the deep fibers, form the major portion of the *brachium pontis*. The *longitudinal fibers*, arranged in bundles or fasciculi and entering the pons from the cerebral peduncles, comprise three tracts—the *corticospinal tract* (fibers which continue through the pons into the pyramids of the medulla and on to the spinal cord), the *corticobulbar tract* (fibers which pass through the pons and end in motor nuclei of cranial nerves in the medulla), and the *corticopontile tract* (whose fibers end in the pontine nuclei). The *pontine nuclei* comprises small masses of motor neurons located between the transverse fibers; axons pass to the opposite side and enter the cerebellum by way of the *brachium pontis*.

The *tegmental portion*, consisting of longitudinal and transverse fibers and gray nuclei, forms the upper portion of the floor of the fourth ventricle. Its longitudinal fiber tracts are in general continuous with those of the medulla oblongata and are arranged in a similar position. Nuclei located in this portion are: *motor nuclei* of the abducens, facial, and trigeminal nerves; and *sensory nuclei* of the trigeminal nerve and the vestibular and cochlear branches of the acoustic nerves.

Functions of the Pons. The pons varolii has the following functions:

1. It contains important fiber tracts connecting the medulla oblongata with the higher centers of the brain.
2. It contains motor and sensory nuclei of three cranial nerves: V (trigeminal), VI (abducens), and VII (facial). It also contains terminal sensory nuclei of the vestibular and cochlear branches of the VIII nerve (acoustic).

CEREBELLUM. The cerebellum lies posterior to the pons and medulla and inferior to the occipital lobes of the cerebral hemispheres. It is

a large, bilobular structure with its surface thrown into laminæ or folds called *folia*. The cerebellum consists of two lateral *hemispheres* and a median unpaired *vermis*. It is connected to other parts of the brain as follows: to the *medulla* by the inferior cerebellar peduncle (restiform body); to the *pons* by the middle cerebellar peduncle (brachium pontis); to the *midbrain* by the superior cerebellar peduncle (brachium conjunctiva).

Structure of the Cerebellum. The cerebellum is composed of gray matter, which comprises an outer layer or *cortex* and several nuclear masses, and an irregular central portion of white matter, the *medulla*. Seen in the sagittal section, the white matter has a tree-like form, for which reason it is named *arbor vitæ*.

The cortex of the cerebellum has two layers of cells: the outer gray *molecular layer* and an inner rust-colored *nuclear* or *granular layer*. Between these layers lies a single row of *Purkinje cells*. These are peculiar-shaped neurons which are characteristic of the cerebellum; the cell body is large and flask-shaped, and from its neck one or two dendrites emerge which pass into the molecular layer, where they divide and subdivide into numerous branches, giving the whole cell a tree-like appearance. A single axon emerges from the bottom of the "flask" and passes through the nuclear layer into the white substance of the medulla. The nuclei of the cerebellum include a large *dentate nucleus* and the smaller *globose*, *emboliform*, and *fastigial nuclei*, all of which are paired.

The white matter is composed of two types of fibers: *projection fibers* (axons and dendrites entering and leaving the cerebellum through the cerebral peduncles); and *fibrae propriae*, (composed of *commissural fibers*, which connect the two hemispheres, and *association fibers*, which connect the folia).

Functions of the Cerebellum. In general, the cerebellum is concerned with the regulation and coordination of complex voluntary muscular movements, without, however, initiating them. (1) It plays a role in the maintenance of muscle tonus. (2) It is involved in reflexes concerned with the maintenance of normal posture and equilibrium, and it serves to mediate vestibular and postural (proprioceptive) impulses. (3) It is essential for the normal timing and integration of voluntary muscular movements, especially those involved in skilled activities. (4) It reinforces muscle contractions, especially those in muscles of the extremities.

MIDBRAIN (MESENCEPHALON). The midbrain forms the uppermost portion of the brain stem. It lies directly above the pons and anterior and slightly superior to the cerebellum. It connects the pons and the cerebellum to the diencephalon and cerebrum, which lie immediately above it. Passing through the central portion is a narrow canal, the

cerebral aqueduct, also known as the *aqueduct of Sylvius*, which connects the third ventricle of the diencephalon with the fourth ventricle of the medulla oblongata.

Structure of the Midbrain. The midbrain consists of two portions: a *ventral portion*, which has two cerebral peduncles; and a *dorsal portion*, or *tectum*, which comprises a four-part body, the *corpora quadrigemina*.

The *ventral portion of the midbrain* consists of two broad bands of diagonal fibers, the *cerebral peduncles*. Inferiorly, the peduncles converge near the midline and enter the superior surface of the pons; superiorly, they enter the lower surface of the cerebral hemispheres. The depressed triangular area between them is called the *interpeduncular fossa*. From the medial surface of each peduncle, the oculomotor (III) nerve emerges, while from the posterolateral surface, in a groove between the peduncles and the pons, emerges the trochlear (IV) nerve. Seen in cross section, each peduncle consists of a dorsal portion (*tegmentum*) and a ventral portion (*base* or *crusta*), the two being separated by a deeply pigmented layer of gray matter, namely, the *substantia nigra*.

The tegmentum is continuous below with the tegmental portion of the pons. It consists of white matter made up of longitudinal and transverse fibers and gray matter made up of nuclei and fiber tracts. Some of the important nuclei found here are:

1. *Oculomotor and trochlear nuclei*, motor nuclei of cranial nerves III and IV.

2. *Dorsal tegmental nucleus*, a portion of which is called the *Edinger-Westphal nucleus*, which gives rise to the efferent fibers passing through the oculomotor nerve to the intrinsic muscles of the eyes.

3. *Mesencephalic nucleus*, thought to be the origin of sensory fibers present in the maxillary branch of the trigeminal (V) nerve.

4. *Red nucleus (nucleus ruber)*, the cells of which contain a red pigment. Afferent and efferent fibers connect this nucleus with the higher centers of the brain, the cerebellum, the pons, and the medulla. This nucleus serves as an important relay station for impulses to and from these regions. It contains the cells of origin of efferent fibers in the rubrospinal tract.

The *dorsal portion of the midbrain (tectum)* is traversed by two grooves, a longitudinal groove and a transverse groove, which divide it into four parts of *colliculi*, two of them superior and two inferior, the whole forming the *corpora quadrigemina*. Extending laterally from each colliculus is a band of fibers or *brachium*. The *superior brachium* extends from the superior colliculus to the *lateral geniculate body* of the thalamus. The *inferior brachium* extends from the inferior colliculus to the *medial geniculate body* of the thalamus.

Functions of the Midbrain. The midbrain has the following functions: (1) It serves as a connecting region between the higher and lower centers of the brain. (2) It contains the motor nuclei of the oculomotor (III) and trochlear (IV) nerves, and other nuclei, among them the red nucleus. (3) It plays an important role in equilibrium and postural reflexes, the center for maintaining equilibrium is located near the red nucleus. (4) The colliculi serve as reflex centers, the superior mediating visual, auditory, and tactile impulses, the inferior mediating auditory impulses.

Diencephalon. The diencephalon lies between the midbrain and the cerebral hemispheres. It includes the thalamus and metathalamus, the epithalamus, and subthalamus, and the hypothalamus. The general relationships between these regions can be observed in a diagram of the midsagittal section. In the center of the diencephalon lies a cavity in the form of a vertical cleft, the *third ventricle*. Inferiorly, it communicates with the fourth ventricle by means of the cerebral aqueduct; laterally, it communicates with the lateral ventricles of the cerebral hemispheres by means of two small openings, the *interventricular foramina of Monro*.

Thalamus (Optic Thalamus) and Metathalamus. The thalamus consists of two large ovoid masses, each about 4 cm. in length, which lie lateral to the third ventricle. Each consists largely of gray matter covered by a thin layer of white matter, the *stratum zonale*. The posterior end presents a medial enlargement, the *pulvinar*, which continues laterally as the *lateral geniculate body*. Directly beneath the pulvinar is an oval mass, the *medial geniculate body*. Connecting the two masses (or thalami) is a flattened band of gray matter, the *intermediate mass* (middle commissure); this mass is not present in all individuals.

The two geniculate bodies, sometimes described as the metathalamus, are small ovoid bodies lying in the posterolateral portion of the thalamus. The medial body receives acoustic fibers from the inferior colliculus of the midbrain and relays their impulses to the temporal lobe of the cortex; the lateral body receives fibers from the optic tract, about three-fourths of such fibers ending here. Impulses of the optic fibers are relayed to the visual areas in the occipital lobe of the cortex.

The thalamus contains a number of nuclei, which are grouped according to their position as follows: midline, anterior, medial, lateral, and posterior. In these nuclei, afferent fibers from cranial nerves or other parts of the brain synapse with neurons whose efferent fibers or axons pass to effector organs or to other parts of the brain. The thalamus thus serves as a relay station.

Epithalamus. This portion of the diencephalon includes the trigonum habenulae, the pineal body, and the posterior commissure.

The *trigonum habenulae* is a triangular depressed area located di-

rectly anterior to the superior colliculus at the base of the pineal stalk. It contains the habenular nuclei, the olfactory correlation centers.

The *pineal body* or *epiphysis* is a conical reddish-gray body about 8 to 10 mm. in length attached by a narrow stalk to the posterior portion of the roof of the third ventricle. The ventricle extends a short distance into the stalk. The function of the pineal body is uncertain. As a vestigial homologue of a light-sensitive organ, or "third eye" present in certain primitive reptiles (*Sphenodon*), it has been regarded as a rudimentary sense organ. It has also been considered to be an endocrine organ whose secretion retards growth and sexual development. However, injections of extracts from the organ have given highly variable results; consequently, its endocrine status is uncertain.

The *posterior commissure*, a round band of white fibers connecting the two halves of the diencephalon, lies just below the pineal stalk and above the aqueduct of Sylvius.

Subthalamus (Ventral Thalamus). This includes the ventrolateral portions of the diencephalon lying anterior and lateral to the midbrain. The red nucleus and the substantia nigra of the midbrain may project into it. The subthalamus contains a band of fibers, the *tegmental field of Forel* and the *nucleus of Forel*. Other smaller nuclei (nucleus subthalamus and zona incerta) are present.

Hypothalamus. The hypothalamus comprises the major portion of the ventral region of the diencephalon and forms most of the floor of the third ventricle. It includes the *optic chiasma*, *mammillary bodies*, *tuber cinereum*, *infundibulum*, and *hypophysis*. The *optic chiasma* is an X-shaped band of fibers lying anterior to the hypophysis. It is continuous anteriorly with the optic nerves and posteriorly with the optic tracts, which lead to the lateral and medial geniculate bodies of the thalamus. In the chiasma, partial decussation of fibers occurs. The *mammillary bodies* are two rounded bodies lying in the floor of the third ventricle between the cerebral peduncles and immediately above the pons. They contain nuclei involved in relaying olfactory impulses. The *tuber cinereum* is a mass of gray matter lying between the optic chiasma and the mammillary bodies. It is bounded laterally by the optic tracts. The *infundibulum* is a hollow, conical process projecting inferiorly and anteriorly from the tuber cinereum. It is continuous with the posterior lobe of the hypophysis. The *hypophysis* (or *pituitary gland* of internal secretion) is an ovoid body attached to the distal end of the infundibular stalk. It consists of an anterior lobe, a pars intermedia, and a posterior lobe, and lies within the sella turcica.

Functions of the Diencephalon. The diencephalon has the following functions:

1. It gives rise to the optic nerve (II), fibers of which pass through the optic chiasma to the retina of the eye.

2. A part of it, the thalamus, is an important relay station for the transmission of afferent impulses from sense organs to the sensory areas of the cerebral cortex.

3. Its various parts contain important reflex centers through which are regulated activities of organs and structures innervated by the autonomic nervous system.

4. A part of it, the hypothalamus, contains the reflex centers for the regulation of body temperature. Through its connections with the hypophysis, it plays an important role in water, fat, and carbohydrate metabolism. It co-ordinates nervous and endocrine activities and is the source of posterior pituitary hormones.

5. The thalamus, hypothalamus, and subthalamus play an important role in emotional behavior. Further, the thalamus serves as a center of primitive uncritical sensation, and may be the seat of certain subjective sensations accompanying emotional experiences. There is some evidence that the thalamus possesses centers controlling sleep and appetite. The subthalamus exerts control over the muscles of emotional expression. The hypophysis, through its internal secretions, regulates many body activities. It is called the "master gland" of the body.

CEREBRUM (CEREBRAL HEMISPHERES). The cerebral hemispheres constitute the largest part of the brain, forming a bilobular mass completely covering the other portions of the brain. The hemispheres are separated by a deep cleft, the *longitudinal cerebral fissure*. Each contains a cavity, the *lateral ventricle*, which communicates with the third ventricle by an opening, the *interventricular foramen of Monro*. The two hemispheres are connected across the midline by a broad band of white fibers, a central white commissure, the *corpus callosum*, and two smaller bands, the anterior and posterior commissures. Each hemisphere consists of an outer layer of gray matter, the *cerebral cortex*, which encloses the inner *white matter*.

Surface Anatomy of the Cerebrum. The surface of the cerebrum is thrown into a large number of folds called *convolutions* or *gyri*. These are separated by furrows, the deeper ones being known as *fissures*, the shallower ones as *sulci*. The gyri and sulci have fairly definite locations, but they vary to some extent in different individuals and even in the two hemispheres of a single brain. The principal fissures (or sulci) are:

| | |
|--------------------------------------|-----------------------------------|
| Lateral fissure (fissure of Sylvius) | } on the lateral surface |
| Central sulcus (fissure of Rolando) | |
| Parieto-occipital fissure | on the superior-dorsal surface |
| Calcarine fissure } | on the medial surface |
| Cingulate fissure } | |
| Collateral fissure } | on the inferior surface |
| Sulcus circularis } | |

The *lobes* into which each hemisphere is divided by the foregoing fissures and sulci can all be seen superficially, with the exception of the insula, which lies internal to the other lobes. The lobes are: (1) frontal lobe, comprising the anterior portion; (2) parietal lobe, comprising the superior-lateral portion; (3) temporal lobe, comprising the inferior-lateral portion; (4) occipital lobe, comprising the posterior portion; and (5) insula (island of Reil, or central lobe), lying inferior to the frontal lobe and internal to the temporal lobe.

The *gyri* are the result of unequal growth processes which greatly increase the surface area of the cerebral cortex. The principal gyri are:

As Seen from the Lateral Surface

In the frontal lobe: { Anterior central gyrus, which contains the motor area
Frontal gyri (superior, middle, and inferior)

In the temporal lobe: Superior, middle, and inferior temporal gyri

In the parietal lobe: { Posterior central gyrus, which contains sensory area
Superior parietal lobule { Supramarginal gyrus
Inferior parietal lobule { Angular gyrus

As Seen on the Medial and Basal Surfaces

In the frontal and parietal lobes: { Superior frontal gyrus
Gyrus cinguli (lies superior to the corpus callosum)
Gyrus fornicatus
Gyrus rectus

In the temporal lobe: { Inferior temporal gyrus
Fusiform gyrus (Parahippocampal gyrus)
Hippocampal gyrus

In the occipital lobe: { Cuneus
Lingual gyrus

Gray Matter of the Cerebral Hemispheres. The gray matter of the cerebrum includes the surface layer or cortex, the basal ganglia, and the nuclei. The two latter constitute the internal gray matter.

The *cerebral cortex* is the surface layer of the cerebral hemispheres. It is variable in thickness, being thinner at the bottom of the sulci and in the occipital region. It can be subdivided into six general layers of alternating white and gray matter. The dendrites of the neurons of the gray matter synapse with other neurons of the cortex or with neurons located in other parts of the brain.

The regions of the cortex differ from each other structurally and functionally. On the basis of histological, experimental, and clinical data, the areas can be classified as sensory, motor, or association areas.

The *sensory areas* receive impulses originating in sense organs or

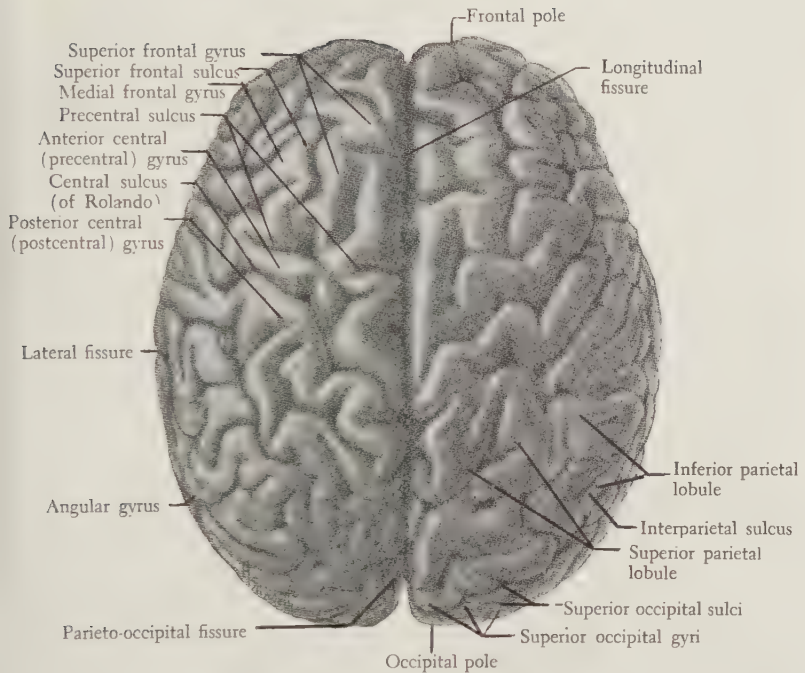


Fig. 4-3. Surface of cerebrum. (Reprinted with permission of Blakiston Division, McGraw-Hill Book Company, from *Morris' Human Anatomy*, 11th ed., edited by J. P. Schaeffer, 1953.)

receptors. It is here that these impulses evoke conscious sensations. The more important of these areas are: (1) *visual area*, located in the occipital lobe in the vicinity of the calcarine fissure and concerned with visual sensations; (2) *auditory area*, located in the temporal lobe and concerned with auditory sensations; and (3) *somesthetic* or *sensory area*, located in the postcentral gyrus of the parietal lobe and concerned with sensations of touch, pressure, position, and temperature.

The *motor area* exercises control over striated or skeletal muscles. It is located in the precentral gyrus immediately anterior to the fissure of Rolando. In this area are found the giant pyramidal cells of Betz, large motor neurons whose axons constitute fibers of the corticospinal and corticobulbar tracts. The axons of these neurons (called upper motor neurons) continue down the spinal cord and synapse with axons located in the anterior horns of the gray matter of the spinal cord. Axons of the latter (called lower motor neurons) innervate the skeletal muscles. Impulses from the motor area control the action of

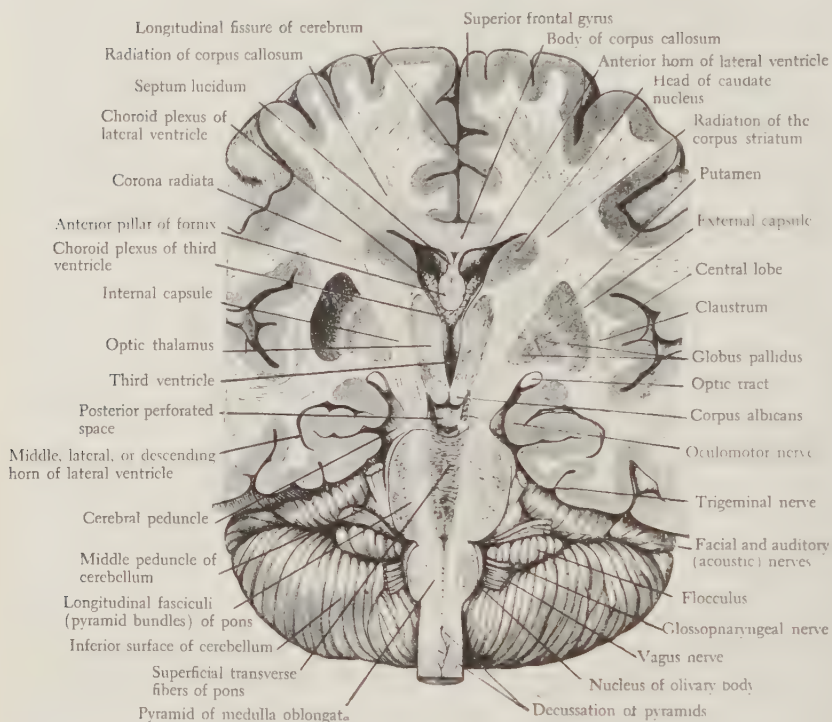


Fig. 4-4. Basal ganglia. Transverse section of the brain in the direction of the medulla oblongata and the cerebral peduncles. The course of the pyramidal tract from the decussation of the pyramids upwards, through the pyramid of the medulla oblongata, the pons varolii, and the crura of the cerebral peduncle or crus cerebri into the internal capsule, where it enters the peduncle of the corona radiata. In the medullary center or white matter of the cerebrum, we see the interlacement of the radiation of the corpus callosum with the fibers of the corona radiata as they diverge from the internal capsule, and with the fibers of the radiation of the corpus striatum. Note the two parts of the corpus striatum (the caudate nucleus and the lentiform nucleus, which is divided into the putamen and the globus pallidus); the white fibers of the internal capsule, which separates the putamen from the caudate nucleus; the fibers of the external capsule, which separates the putamen from the triangular claustrum; the large, ovoid thalamus (optic thalamus), which is separated from its fellow on the opposite side by the third ventricle; the septum pellucidum, which separates the anterior, posterior, and inferior horns of the lateral ventricle; the choroid plexus, which is located in the roof of the third ventricle; and the choroid plexus of the lateral ventricle. (Reprinted with permission of The Macmillan Company from Toldt, *Atlas of Human Anatomy*, Vol. II.)

specific muscles. Just anterior to the motor area is a *premotor area*, the neurons of which control whole series of movements.

Experiments show that the motor area of one hemisphere controls the contraction of muscles on the opposite side of the body. This is explained by the fact that most of the axons of the pyramidal cells in their passage downward through the brain and spinal cord cross to the opposite side. This occurs principally in the medulla in the decussation of the pyramids. Consequently, injury to the motor area in one hemisphere (as from skull fracture or cerebral hemorrhage) results in paralysis of muscles on the opposite side of the body.

The *association areas* comprise most of the cerebral cortex that is not included in the sensory and motor areas. They are connected with each other, with motor and sensory areas, and with similar areas in the opposite hemisphere. They also receive numerous fibers from the thalamus. Damage or injury to certain association areas result in defects of speech and in failure to understand word meanings. A specific area known as *Broca's area* lies in the left inferior frontal gyrus just above the lateral fissure; it was described by Broca as the center for articulate speech. Another, *Wernicke's center*, also called the parolfactory area, is found in the cortex of the left temporo-occipital convolution anterior to the subcallosal gyrus; it is associated with inability to understand spoken language (injury to the area results in aphasia). It is not known precisely how these association areas function, but it is thought that they constitute the anatomical basis for most of our behavior, especially that which involves learning and memory.

The *basal ganglia* include several masses of gray matter located in the basal portion of each cerebral hemisphere. They are the corpus striatum, the amygdaloid nuclei, and the claustrum.

The *corpus striatum* consists of two portions: a dorsal part (*caudate nucleus*) and a ventral part (*lentiform nucleus*); the latter is divided into the *putamen* and the *globus pallidus*. The caudate nucleus and the putamen are separated by a band of white fibers, the *internal capsule*, which gives the structure a striated appearance; hence the name, corpus striatum. The internal capsule also separates the lentiform nucleus from the thalamus, which is located medially to it. Lateral to the lentiform nucleus is another band of fibers, the *external capsule*, which separates it from the *claustrum*, a triangular mass lying beneath the cortex of the insula. The *amygdaloid nuclei* consists of a mass of nuclei located in the roof of the inferior horn of the lateral ventricle. Scattered throughout the basal portions of the cerebral hemispheres are other nuclei not included in the basal ganglia. These nuclei serve as centers for the integration of various body activities.

The functions of the basal ganglia have not yet been definitely es-

tablished, but it is believed that they play an important role in the coordination of voluntary muscular activities. Paralysis agitans (Parkinson's disease), characterized by tremor, muscle weakness, and delay in voluntary motor reaction, and Sydenham's chorea (St. Vitus' dance), characterized by muscular twitching, are thought to be due to lesions involving the basal ganglia.

White Matter of the Cerebral Hemispheres. The white matter of the cerebral hemispheres consists of three kinds of myelinated nerve fibers: *projection fibers*, *association fibers*, and *commissural fibers*.

Projection fibers connect the cortex with the lower parts of the brain and the spinal cord. They are of two types: (1) afferent or ascending fibers, which arise from cell bodies located principally in the thalamus, and (2) efferent or descending fibers, which arise from cell bodies located in the motor area of the cerebral cortex and pass through the corona radiata and the internal capsule to the brain stem, where they form the *corticospinal*, *corticobulbar*, and *corticopontine tracts*.

Association fibers consist of axons which connect the gyri of the same hemisphere. Some are short fibers connecting adjacent gyri; others are long fibers connecting widely separated gyri.

Commissural fibers are transverse fibers leading from the gyri of one hemisphere to those of the other hemisphere. They are grouped into three bands: the corpus callosum and the anterior and posterior commissures. The *corpus callosum* is a thick, transverse band of fibers which, in a midsagittal section of the brain, appears as a large, arched band lying in the central portion of the brain. It lies over the region of the thalamus and the septum pellucidum. Its anterior end is called the *genu*, its posterior end the *splenium*. The *anterior commissure* is a small transverse band of fibers lying anterior to the fornix in the anterior wall of the third ventricle. The *posterior commissure* is a band of fibers crossing the midline near the base of the stalk of the pineal body.

RHINENCEPHALON OR OLFACTORY BRAIN. The rhinencephalon is that portion of the cerebrum which is involved in the reception and integration of olfactory impulses. It includes the following seven structures:

1. *Olfactory bulb*, an oval mass lying beneath the frontal lobe and directly above the nasal cavity. It receives the olfactory nerves which pass upward through the cribriform plate from the olfactory region of the nasal cavity.

2. *Olfactory tract*, a band of fibers passing posteriorly from the bulb. On entering the substance of the cerebrum, it divides into two bands: the *lateral* and *medial olfactory striae*.

3. *Olfactory trigone*, a small triangular area lying between the diverging striae. Posterior to it is the *olfactory tubercle*, which forms a

part of the *anterior perforated substance* which extends from the olfactory striae to the optic tract.

4. *Piriform area*, an area including the *hippocampal gyrus*, the *uncus*, and the *lateral olfactory sulcus*.

5. *Hippocampal formation*, a structure which includes the *subcallosal gyrus*, the *supracallosal gyrus*, the *longitudinal striae* of the corpus callosum, the *diagonal band of Broca*, the *dentate gyrus*, and the *hippocampus*. These parts lie along the medial wall of each cerebral hemisphere. The hippocampus is an elevated area lying along the floor of the inferior horn of each lateral ventricle.

6. *Paraterminal body*, a triangular area of the cortex anterior to the *lamina terminalis* which forms anterior wall of 3rd ventricle.

7. *Fornix*, a paired, curved structure lying over the thalamus and under the corpus callosum. It consists of two *crura*, whose anterior ends, the *fimbriae*, lie adjacent to the hippocampus. As the crura curve upward over the thalamus, they unite in the median plane to form the *body of the fornix*. Anteriorly, the crura diverge and curve downward to form the *anterior pillars*. Posteriorly, the crura are connected by the *hippocampal commissure*; anteriorly, by the *anterior commissure*.

The *septum pellucidum* is a thin sheet of nervous tissue consisting of two layers, or laminae. It is triangular in shape and is attached to the corpus callosum above and the fornix below. Each lamina forms the medial wall of the lateral ventricle of each hemisphere. Between the two laminae is a narrow cleft-like cavity, the so-called "fifth ventricle," which is not a true ventricle.

THE MENINGES

The brain and the spinal cord are each enclosed by three membranes called *meninges*; these are the *dura mater*, the *arachnoid*, and the *pia mater*. The meninges of the brain differ in some respects from those of the spine.

Cranial Meninges. These membranes enclosing the brain have the following characteristics.

DURA MATER. This is a tough, fibrous membrane forming the outermost covering of the brain. It is dense and inelastic. The dura mater consists of two layers: the *endosteal layer* and the *inner meningeal layer*. The endosteal layer lines the bones of the cranial cavity and functions as the periosteum of these bones. At the foramina of the skull it forms an investing layer surrounding the cranial nerves and is continuous with the external periosteum on the cranial bones. The inner meningeal layer of the dura mater is smooth and lined with mesothelium.

Over the surface of the brain, folds or processes of the dura mater

dip in between the various parts, forming partitions. The more important of these folds are:

1. *Falx cerebri*, a sickle-shaped fold which lies in the longitudinal fissure separating the two cerebral hemispheres.

2. *Tentorium cerebelli*, a fold which lies between the cerebellum and the occipital lobes of the cerebral hemispheres.

3. *Falx cerebelli*, a triangular fold lying in the midline between the cerebellar hemispheres.

4. *Diaphragma sellae*, a small, circular, horizontal fold which encircles the *infundibulum* and forms a roof-like structure over the hypophysis.

ARACHNOID. This is a thin, delicate layer lying internal to the dura mater, from which it is separated by a very narrow subdural space. It does not dip into the fissures or sulci, with the exception of the longitudinal fissure.

Between the arachnoid and the pia mater is a space, the *subarachnoid space*. Over the surface of the hemispheres the cavity is very narrow, but at the lower portions of the sulci triangular-shaped spaces are formed. The subarachnoid space is traversed by numerous delicate *trabeculae*, which gives the space a sponge-like appearance. At the base of the brain the arachnoid is separated from the pia mater, giving rise to spaces of considerable depth, called *subarachnoid cisternae*. The subarachnoid space is filled with cerebrospinal fluid. It communicates with the fourth ventricle.

The arachnoid (and, in particular, the arachnoid cisternae) is a protective structure, serving as a fluid-filled, web-like cushion separating the brain from the cranial bones, with which it would otherwise be contiguous.

At certain places, especially in the floor of the superior sagittal sinus, the arachnoid develops evaginations which, with the overlying dura mater, project into the cavity of the sinus. These are *arachnoid villi* or *Pacchionian bodies*. Through these villi the cerebrospinal fluid re-enters the blood stream. Arachnoid villi may also appear on the surface of the hemispheres, where they may project into the inner surface of the cranial bones, giving the bones a pitted appearance. Here they are called *arachnoid granulations*.

PIA MATER. This is the innermost membrane. It is a highly vascular membrane which closely invests the brain, dipping into all the fissures, furrows, and sulci. It consists of fine, areolar tissue and mesothelial cells, and contained within it are numerous blood vessels supplying the brain. At certain places the pia mater is invaginated into the ventricles to form the *choroid plexuses* (described on page 101).

Spinal Meninges. The three membranes which enclose the brain are continuous at the *foramen magnum* with the three membranes of

the same names which enclose the spinal cord. However, they differ in some respects, as stated below:

The *dura mater* in the vertebral canal is separated from the periosteum of the vertebrae by the *epidural space*, which contains loose connective and adipose tissue and many veins. On each side the dura is firmly connected to the cord by *dentate ligaments* of the pia mater. The dura mater forms tubular projections which invest the roots of the spinal nerves. These continue outward a short distance through the intervertebral foramina. The dura is separated from the arachnoid by a narrow space, the *subdural space*.

The *arachnoid* of the brain and the spinal cord are similar in structure. The *subarachnoid space* is wider in the cord than in the brain, especially in the lower part of the vertebral canal.

The *pia mater* of the spinal cord is denser than that of the brain and contains fewer blood vessels. Along the side of the cord, triangular processes, twenty in number, extend from the pia mater and connect with the dura mater. These are extensions of a band that extends along each side of the spinal cord, separating the roots of the spinal nerves. This band is called the *dentate ligament*.

Sometimes the pia mater and the arachnoid are regarded as one membrane, in which case it is called the *pia-arachnoid* or *leptomeninges*.

Ventricles, Choroid Plexuses, and Cerebrospinal Fluid. In the development of the central nervous system (see pp. 80–82), the cavities of the primitive neural tube persist. In the brain these enlarge and form definite cavities or *ventricles*, which communicate with each other and are continuous with the *central canal* of the spinal cord.

VENTRICLES OF THE BRAIN. The *first* and *second* (or lateral) *ventricles* lie in the two cerebral hemispheres. Each consists of a body bearing three extensions: the *anterior*, *posterior*, and *inferior horns* (cornua). They are separated from one another by the septum pellucidum and communicate with one another by the *interventricular foramina*. The *third ventricle* is a narrow cleft-like cavity lying in the midsagittal plane between the thalami. It communicates with the fourth ventricle by a cerebral canal known as the *aqueduct of Sylvius*, which passes through the midbrain. The *fourth ventricle* lies principally in the medulla. It is roughly quadrangular in shape, its upper and lower corners forming the *superior* and *inferior angles*, its lateral corners forming the *lateral recesses*. It is lined with epithelium. The *floor* of the fourth ventricle is formed by the pons and the medulla oblongata; its roof or dorsal wall is divided into three regions: the *superior* region, formed by the anterior medullary vela and superior peduncles; the *intermediate* region, formed by the cerebellum; and the *inferior* region, formed by the meninges. The *roof* of the fourth ven-

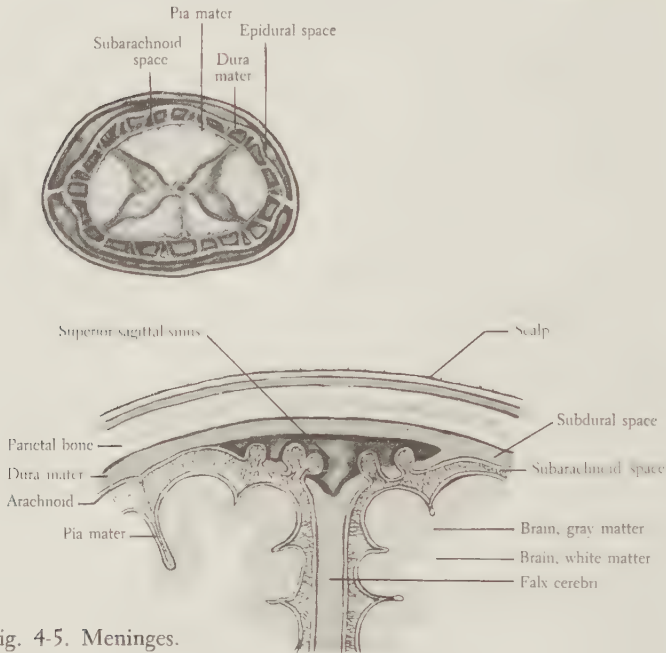


Fig. 4-5. Meninges.

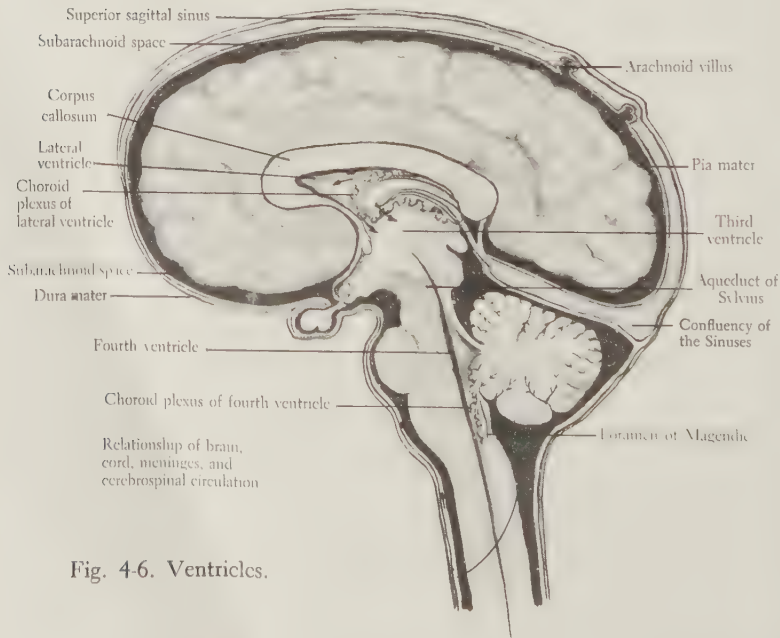


Fig. 4-6. Ventricles.

tricle has three openings: a medial *foramen of Magendie* and two lateral *foramina of Luschka*. Through these openings the fourth ventricle communicates with the subarachnoid spaces of the meninges. At the superior angle, the fourth ventricle is continuous with the cerebral aqueduct (aqueduct of Sylvius); at the inferior angle, it is continuous with the central canal of the spinal cord.

CHOROID PLEXUSES. In certain areas, the brain wall retains its early embryonic character and persists as thin, non-nervous epithelium. At these places, the pia mater becomes modified, forming the *tela choriodea*, from which highly vascular structures, *choroid plexuses*, develop. Each choroid plexus is a much-folded structure which projects into a ventricle. It presents a relatively large surface to the cerebrospinal fluid that fills the ventricle. Choroid plexuses are found in the walls and roof of each of the lateral ventricles and in the roofs of the third and fourth ventricles. They play an important role in the formation of the cerebrospinal fluid.

CEREBROSPINAL FLUID. The cerebrospinal fluid fills the ventricles of the brain, the central canal of the spinal cord, and the subarachnoid and subdural spaces. It is a clear, colorless fluid of watery consistency having a specific gravity of 1.006. It contains proteins (about 0.03 per cent), glucose, urea, salts, and usually a few leucocytes (average 6 cells per cu. ml.).

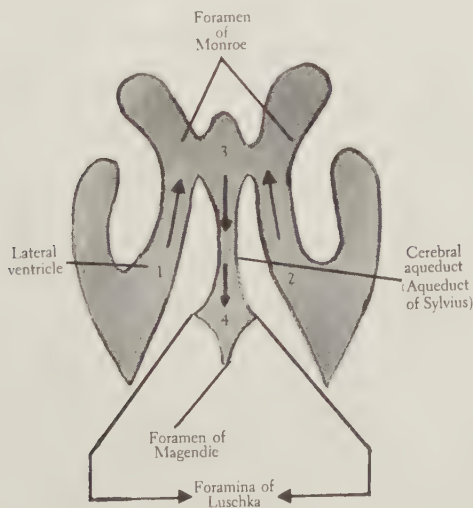


Fig. 4-7. Diagram of ventricles showing flow of cerebrospinal fluid.

Function of Cerebrospinal Fluid. The cerebrospinal fluid, which fills the subarachnoid space, serves as a fluid cushion protecting the brain and the spinal cord from mechanical shocks and as a source of nutritive substances.

Formation and Circulation of Cerebrospinal Fluid. The cerebrospinal fluid is formed principally by the choroid plexuses of the ventricles. It is believed to come about by the processes of filtration and dialysis, although active secretion by the epithelial cells may also take place. The fluid formed in the lateral ventricles passes (circulates) through the interventricular foramina (foramina of Monro) to the third ventricle. There more is added, and it flows on through the aqueduct of Sylvius to the fourth ventricle, where further accretions occur. Fluid accumulating in the fourth ventricle escapes into the subarachnoid space through the two foramina of Luschka and the foramen of Magendie. It passes *downward* in the subarachnoid space on the dorsal surface of the spinal cord and *upward* in the space of the ventral surface. Eventually, the cerebrospinal fluid makes its way through the subarachnoid space of the brain to the arachnoid villi, which extend into the superior sagittal sinus where it is reabsorbed into the blood stream. It may also re-enter the blood by way of the perilymphatic vessels which drain the brain.

Cerebrospinal fluid is being formed continually. Normally, it is reabsorbed as rapidly as it is formed. The total amount present at any one time averages from 100 to 150 cc. About 400 cc. of fluid is formed every 24 hours.

THE SPINAL CORD

The spinal cord is that portion of the central nervous system lying outside the cranial cavity. It is located within the vertebral canal of the spinal column.

Functions of the Spinal Cord. The spinal cord performs two general functions:

1. *It is a conducting pathway.* Afferent impulses from the periphery and efferent impulses from the brain are conducted through the fibers of the white matter of the cord.

2. *It serves as a reflex center.* In the gray matter of the cord connections can be made between afferent and efferent neurons which provide the basis for reflex action.

Structure of the Spinal Cord. The spinal cord is an elongated cylindrical structure extending from the foramen magnum to the second lumbar vertebra. It averages 42 to 45 cm. in length, being slightly longer in males than in females. Its average weight is 30 gm.

The cord consists of a series of segments, 31 in number. Each segment gives rise to a pair of spinal nerves, and each of these is attached

to the cord by two roots: a *dorsal root*, which contains afferent or sensory fibers, and a *ventral root*, which contains efferent or motor fibers. The segments of the spinal cord are continuous one with the other, no external lines of demarcation being visible between them.

Superiorly, the spinal cord is continuous with the medulla oblongata; inferiorly it tapers to a conical portion, the *conus medullaris*, whose extreme tip forms a delicate filament, the *filum terminale* extending to the coccyx. The lower portion of the spinal cord and the roots of the spinal nerves which emerge from it constitute the *cauda equina*.

The spinal cord bears two enlargements, an upper or cervical and a lower or lumbar. The *cervical enlargement* lies between the third cervical and the second thoracic vertebrae; from this region nerves pass laterally to the upper extremity. The *lumbar enlargement* lies at the level of the lower thoracic vertebrae, being broadest at the twelfth; from it extend the roots of the nerves leading to the lower extremity, but instead of passing laterally the nerves follow an oblique course downward in the vertebral canal to reach their point of exit in the lower vertebrae and the sacrum.

In a cross section of the spinal cord, the following can be noted: It consists of two symmetrical halves joined in the midregion by a transverse band of fibers, the *white and gray commissures*, in the center of which is a small opening, the *central canal*. The halves are separated by the *anterior median fissure* and the *posterior median septum*. On the posterior surface there is a median depression, the *posterior median sulcus*.

Gray Matter and White Matter of the Spinal Cord. The substance of the spinal cord consists of gray matter and white matter enclosed within the meninges. The gray matter, composed of neuroglia, neurons, and fine interlacing nerve fibers, is centrally located. The white matter forms the outer substance, enclosing the gray matter. It is composed of neuroglia and nerve-cell processes or fibers, principally medullated axons. The white matter also contains some blood vessels and inward extensions of the pia mater.

PROPORTIONS OF WHITE AND GRAY MATTER. The proportion of white and gray matter varies at different levels of the spinal cord. In the regions of the cervical and lumbar enlargements the amount of gray matter is relatively greater, owing to the presence of large numbers of neurons which send their axons to the extremities. In the upper portions of the cord, the amount of white matter is relatively greater because it contains a much larger number of afferent fibers received from the various spinal nerves.

GRAY MATTER. The gray matter of the spinal cord consists of an H-shaped mass comprising two halves connected by a transverse band

in the center of which is an opening, the *central canal*. The portion of the transverse band in front of the central canal is the *anterior white commissure*; that behind it is the *posterior gray commissure*. The central canal extends the entire length of the cord. Superiorly, it opens into the fourth ventricle of the brain; inferiorly, the canal terminates in the *filum terminale*. Each of the lateral halves of the gray matter is somewhat crescent-shaped and consists of three regions:

1. The *anterior* or *ventral column*. Also called the "ventral horn," this short rounded structure does not approach the surface of the cord; it is occupied principally by the cell bodies of large motor neurons.

2. The *posterior* or *dorsal column*. A longer and more slender portion which is directed laterally and extends almost to the surface of the cord. Its cells are internuncial neurons, also called adjustor cells or secondary sensory neurons, which receive and transmit impulses from the primary sensory neurons of the dorsal roots of spinal nerves.

3. The *lateral column*. Seen only in the upper cervical, thoracic, and midsacral portions of the spinal cord, this lateral-protruding mass contains the cell bodies of preganglionic neurons of the autonomic nervous system.

WHITE MATTER. The white matter in each half of the spinal cord is divided by the gray matter into three general regions, or *funiculi*:

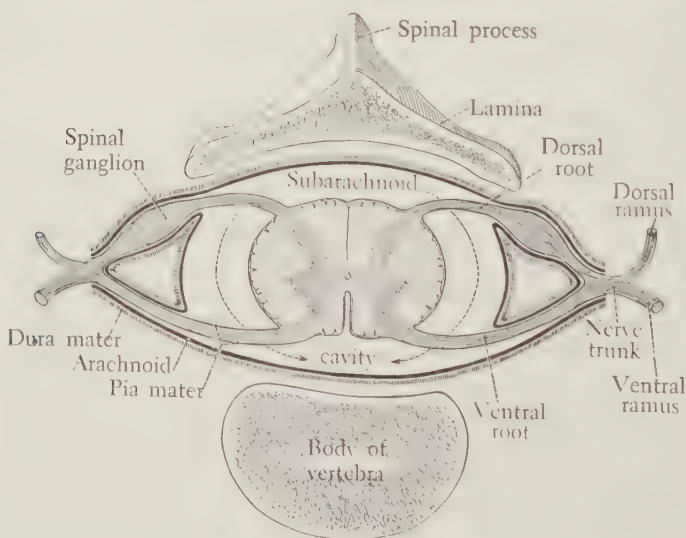


Fig. 48. Cross section of spinal cord. (Reprinted with permission of W. B. Saunders Company from Millard, King, and Showers, *Human Anatomy and Physiology*, 4th ed., 1956.)

the *dorsal funiculus*, the region between the dorsal median septum and posterolateral sulcus (the latter being a groove along which the dorsal roots of the spinal nerves connect with the cord); the *lateral funiculus*, the region between the lines of attachment of the dorsal and ventral roots of the spinal nerves; and the *ventral funiculus*, the region between the ventral root fibers and the anterior median fissure.

The nerve fibers of the white matter are of three types: (1) those which conduct impulses to the brain (sensory fibers) and from the brain (projection fibers), (2) those which connect various segments of the cord with each other (*intersegmental* or *association fibers*), and (3) those that cross the midline (*commissural fibers*).

The fibers to and from the brain are grouped together into bundles called *fiber tracts*. In these tracts, the fibers are principally axons whose cell bodies are located in one of three regions: (1) the dorsal root ganglia of spinal nerves, (2) the gray matter of the brain, or (3) the gray matter of the spinal cord. The fibers of a single tract arise in general from a common point of origin, carry the same type of impulses, and have a common termination. In a funiculus, fibers of one tract may intermingle with those of a similar tract. Such a mixed bundle is called a *fasciculus*. The names of tracts in general indicate their origin and destination and the direction the impulses travel. The lateral corticospinal tracts, for example, which carry impulses originating in the cerebral cortex, descend and terminate in the gray matter of the cord, and are located in the lateral funiculus.

There are two types of tracts: (1) *ascending tracts*, containing afferent fibers which carry impulses toward the brain; (2) *descending tracts*, containing efferent fibers which carry impulses from the brain to the lower levels of the cord.

The principal fiber tracts are given in the following table:

| Location | Ascending Tracts | Descending Tracts |
|------------------------|---|---|
| In anterior funiculus | Ventral spinothalamic tract | { Ventral corticospinal tract Vestibulospinal tract Tectospinal tract |
| In lateral funiculus | { Dorsal spinocerebellar tract Ventral spinocerebellar tract Lateral spinothalamic tract Spinotectal tract | { Lateral corticospinal tract Rubrospinal tract |
| In posterior funiculus | { Fasciculus gracilis Fasciculus cuneatus | |

ASCENDING TRACTS AND FASCICULI. The locations and functions of these tracts are as follows.

Ventral Spinothalamic Tract. This tract consists of fibers whose cell bodies lie in the gray matter in the opposite side of the cord. Most

of the fibers end in the thalamus, but some terminate in the medulla or upper portion of the cord. They convey impulses of tactile sensibility.

Dorsal and Ventral Spinocerebellar Tracts. These pathways consist of fibers whose cell bodies lie in the gray matter of the spinal cord. The fibers may or may not cross to the opposite side of the cord. They reach the cerebellum by way of the superior and inferior cerebellar peduncles, conveying to it proprioceptive impulses from muscles and tendons.

Lateral Spinothalamic Tract. This tract consists of fibers whose cell bodies lie in the gray matter of the opposite side of the cord. They convey impulses which give rise to sensations of pain and temperature. The ascending fibers end in the thalamus.

Spinotectal tract. This tract consists of fibers which arise from cells in the posterior column of the gray matter. They cross to the opposite side of the cord and pass upward, terminating in the roof (tectum) of the midbrain. They convey impulses of pain, temperature, and touch.

Fasciculus Gracilis and Fasciculus Cuneatus. These pathways are composed of fibers whose cell bodies lie in the dorsal root ganglia of spinal nerves. They convey proprioceptive impulses from receptors located in muscles, tendons, and joints and also tactile impulses from receptors in the skin. The fibers terminate in the nucleus gracilis and nucleus cuneatus located in the medulla oblongata. Here secondary neurons convey the impulses to the thalamus on the opposite side where they are relayed to the sensory areas of the cerebral cortex.

DESCENDING TRACTS. The location and functions of these tracts are as follows.

Lateral and Ventral Corticospinal Tracts. The fibers constituting these tracts arise from pyramidal cells of the motor areas of the cerebral cortex. On passing through the medulla, the fibers undergo partial decussation, the majority crossing to the opposite side in the decussation of the pyramids and continuing downward in the spinal cord as the *lateral corticospinal tract*. Fibers extend as far as the fourth sacral segment. In their course they give off collaterals which enter the gray matter and synapse with internuncial neurons or lower motor neurons. The *ventral corticospinal tract* consists of fibers which do not cross in the medulla but continue downward on the same side of the cord. The fibers terminate in the same fashion as those of the lateral corticospinal tract.

Vestibulospinal Tract. The fibers of this tract arise from cells located in the lateral vestibular nucleus nerve located in the medulla oblongata. They pass downward in the anterior funiculus, forming a narrow band near the surface of the cord. They carry impulses involved in muscle tonus and equilibrium.

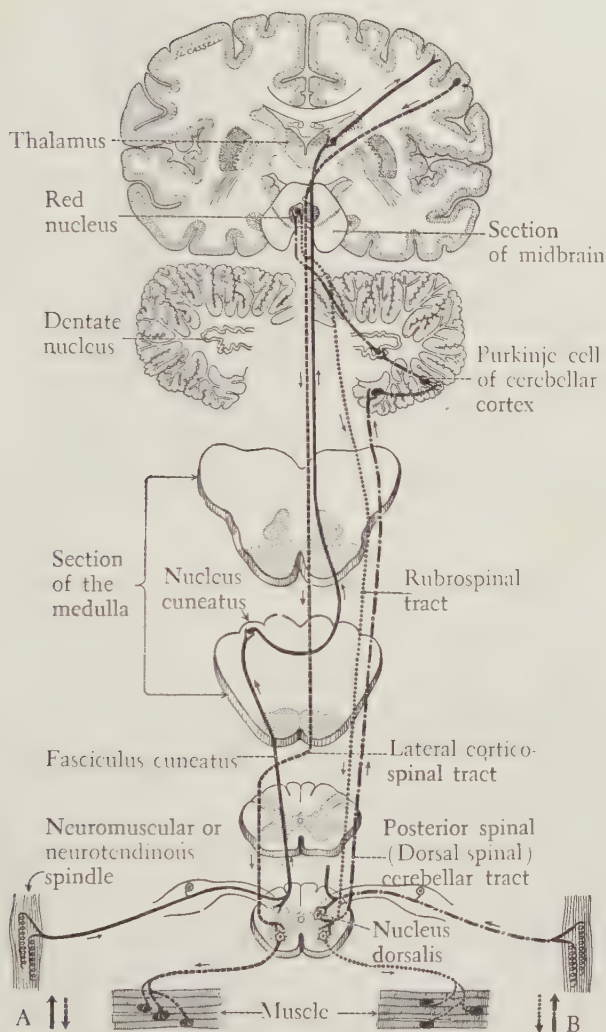


Fig. 4-9. Diagram showing pathways of muscle sense impulses. A, Conscious muscle sense impulses. B, Unconscious muscle sense impulses. (Reprinted with permission of W. B. Saunders Company from Millard, King, and Showers, *Human Anatomy and Physiology*, 4th ed., 1956.)

Tectospinal Tract. The fibers of this tract originate from cell bodies located in the roof of the midbrain. The fibers cross to the opposite side and descend in the anterior funiculus. Collaterals and terminal endings enter the gray matter, where they synapse with motor neurons. They are involved in optic and auditory reflexes.

Rubrospinal Tract. The fibers of this tract originate from cells located in the red nucleus of the midbrain. They cross to the opposite side and pass downward in the cord in the lateral funiculus. The tract is not well developed in man.

The conduction pathways of the spinal cord have been determined by the following methods: (1) by stimulation of specific bundles or areas in sections and noting resulting actions or effects; (2) by section of fiber tracts in experimental animals and noting resulting actions or effects; (3) by utilizing the principle of Wallerian degeneration in which an axon severed from its cell body degenerates. Fibers in ascending tracts degenerate *above* the point of injury; those in descending tracts degenerate *below* the point of injury; (4) by following the embryological development of axons; (5) by using differential staining methods which enable axons to be traced to their cells of origin; (6) by noting the effects of lesions, such as those resulting from infections, tumors, or trauma. Lesions involving ascending tracts bring about loss of sensation; those involving descending tracts, loss of movement.

THE PERIPHERAL NERVOUS SYSTEM

The peripheral nervous system includes those structures which connect the various parts of the body to the brain and the spinal cord. It comprises the craniospinal nerves and the sympathetic division of the autonomic nervous system.

Craniospinal Nerves. As previously described, a nerve is composed of nerve-cell processes or fibers. Nerves may be classified as (1) *afferent* or *sensory* (carrying impulses from receptors to the brain or the spinal cord), (2) *efferent* or *motor* (carrying impulses from the brain or spinal cord to effector organs), and (3) *mixed* (containing both afferent and efferent fibers).

The *functional components* of nerves are the nerve fibers, which transmit impulses. These fibers are either afferent or efferent.

AFFERENT FIBERS. These fibers conduct impulses *to* the brain or spinal cord. They are of the following types: (1) *general somatic afferent*, which conduct impulses from end organs of touch, pressure, heat, cold, and pain, and from proprioceptors; (2) *special somatic afferent*, which conduct impulses from the ear and the eye; (3) *general visceral afferent*, which conduct impulses from sensory nerve endings in the viscera; and (4) *special visceral afferent*, which conduct impulses from end organs of taste and smell.

EFFERENT FIBERS. These fibers conduct impulses *from* the brain or spinal cord. They are of the following types: (1) *general somatic efferent*, which conduct impulses to all striated muscles with the exception of branchiomeric muscles; (2) *general visceral efferent*, which

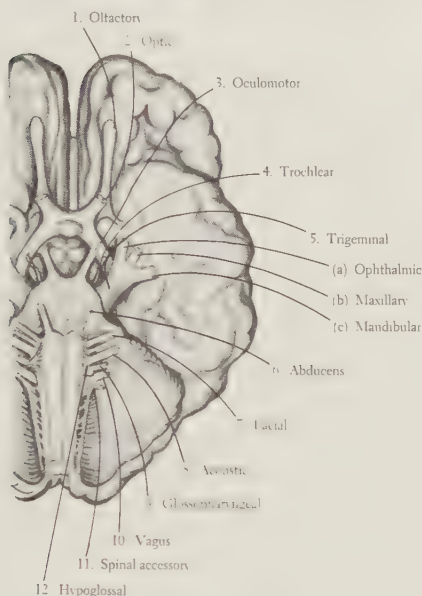


Fig. 4-10. Origins of cranial nerves.

conduct impulses to smooth muscles, cardiac muscles, and glands; and (3) *special visceral efferent*, which conduct impulses to branchiomeric (striated) muscles derived from the branchial arches of the embryo.

Cranial Nerves. Twelve pairs of cranial nerves are attached to the brain. They pass through foramina in the base of the cranium to reach their terminations. Most are mixed nerves, having both motor and sensory fibers, although a few contain only the sensory ones. The sensory or afferent fibers have their cell bodies in ganglia lying outside the brain; the cell bodies of the motor or efferent fibers lie in the nuclei of origin within the brain. The cranial nerves are identified by numbers as well as names. They are:

| | |
|----------------|-------------------------|
| I Olfactory | VII Facial |
| II Optic | VIII Acoustic |
| III Oculomotor | IX Glossopharyngeal |
| IV Trochlear | X Vagus (Pneumogastric) |
| V Trigeminal | XI Spinal Accessory |
| VI Abducent | XII Hypoglossal |

(A small nerve, the *nervus terminalis*, was discovered after the other nerves had been numbered. It is the most anterior cranial nerve, originating from the cerebral hemisphere and passing, with the olfactory nerve, to the septum of the nose. Its functions have not yet been clearly established.)

THE CRANIAL NERVES—PART I

| <i>Nerve</i> | <i>Type of Nerve</i> | <i>Superficial Origin</i> | <i>Deep Origin of Efferent Fibers</i> | <i>Exit from Cranium</i> |
|-------------------------|----------------------|--|--|---|
| I Olfactory | Sensory | Olfactory bulb | None | Cribriform plate of ethmoid |
| II Optic | Sensory | Optic chiasma | None | Optic foramen |
| III Oculomotor | Mixed | Medial surface of cerebral peduncle of mid-brain | Motor nucleus in floor of mid-brain | Supraorbital fissure |
| IV Trochlear | Mixed | Between cerebral peduncle and pons | Trochlear nucleus in mid-brain | Supraorbital fissure |
| V Trigeminal | Mixed | From side of pons near superior border | Motor nucleus in pons | Three branches through supra-orbital fissure, foramen rotundum, and foramen ovale |
| VI Abducens | Mixed (?) | From a groove between pons and medulla | Abducent nucleus in pons | Supraorbital fissure |
| VII Facial | Mixed | (Same as above) | Motor nucleus in pons | Internal acoustic (auditory) meatus and stylohyoid foramen |
| VIII Acoustic | Sensory | (Same as above) | None | Internal acoustic meatus |
| IX Glossopharyngeal | Mixed | Posterolateral sulcus of medulla | Nucleus ambiguus and inferior salivary nucleus in medulla | Jugular foramen |
| X Vagus (Pneumogastric) | Mixed | Posterolateral sulcus of medulla | Nucleus ambiguus and dorsal motor nucleus in medulla oblongata | Jugular foramen |
| XI Spinal accessory | Motor (?) | Posterolateral sulcus of medulla | Nucleus ambiguus of the medulla | Jugular foramen |
| XII Hypoglossal | Mixed | Anterolateral sulcus | Hypoglossal nucleus in medulla | Hypoglossal foramen |

THE CRANIAL NERVES—PART II

| <i>Nerve</i> | <i>Functional Components</i> | <i>Structures Innervated by Afferent Fibers and Sensation Mediated</i> | <i>Structures Innervated by Efferent Fibers, and Reaction Initiated</i> |
|----------------|---|---|--|
| I Olfactory | Special visceral afferent | Olfactory epithelium (smell) | None |
| II Optic | Special somatic afferent | Retina of eye (sight) | None |
| III Oculomotor | General somatic efferent General visceral efferent General somatic afferent | Eye muscles Superior rectus Medial rectus Inferior rectus Inferior oblique Eyelid muscle Levator palpebrae (muscle sense) | Eye muscles—for movement Superior rectus Medial rectus Inferior rectus Inferior oblique Eyelid muscle—for movement Levator palpebrae Ciliary muscles—for accommodation Iris—for constriction |
| IV Trochlear | General somatic efferent | Eye muscle Superior oblique (muscle sense) | Eye muscle—for movement Superior oblique |
| V Trigeminal | | | |
| 1 Ophthalmic | General somatic afferent General visceral efferent | Cornea, ciliary body, lacrimal gland, conjunctiva; mucous membranes of nasal cavity and sinuses; skin of eyelids, eyebrows, forehead, and nose (pain, cold, heat, touch) | None |
| 2 Maxillary | General somatic afferent General visceral efferent | Dura mater; gums and teeth of upper jaw, upper lip; nasal mucosa, orbit | None |
| 3 Mandibular | General somatic afferent Special visceral efferent | Ant. two-thirds of tongue (taste); gums and teeth of lower jaw; skin and mucous membrane of cheek and lower lip (pain, temperature, touch); muscles of mastication (muscle sense) | Muscles of mastication (movement) |

THE CRANIAL NERVES—PART II (*Continued*)

| <i>Nerve</i> | <i>Functional Components</i> | <i>Structures Innervated by Afferent Fibers and Sensation Mediated</i> | <i>Structures Innervated by Efferent Fibers, and Reaction Initiated</i> |
|---------------------|--|---|--|
| VI Abducens | General somatic efferent | (?) | Lateral rectus muscle (movement) |
| VII Facial | General somatic efferent General somatic afferent General visceral efferent Special visceral efferent | Ant. two-thirds of tongue (taste); muscles of neck, face, jaw, scalp, and auricle (muscle sense) | Muscles of neck, face, jaw, scalp, auricle (movement); submaxillary, sublingual, lacrimal, nasal, palatine glands (secretion) |
| VIII Acoustic | Special somatic afferent | Cochlea of ear (hearing); vestibule and semi-circular canals (sense of equilibrium) | None |
| IX Glossopharyngeal | General visceral afferent Special visceral afferent General visceral efferent Special visceral efferent | Mucous membrane of pharynx, fauces, palatine tonsil, and posterior third of tongue (taste, swallowing reflex); carotid sinus (cardiac reflex), skin of ear (cutaneous senses) | Striated muscles of pharynx (swallowing movements); parotid gland (secretion) |
| X Vagus | Same as above | Mucosa of pharynx, larynx, trachea, bronchi (respiratory reflexes); lungs (Herring-Breuer reflex); aortic arch (cardiac reflex); abdominal viscera (hunger, pain) | Muscles of palate, pharynx, and esophagus (swallowing); cardiac muscle (inhibition); smooth muscles of thoracic and abdominal viscera (contraction and inhibition); glands of stomach, intestine, pancreas, and liver (stimulation and inhibition) |
| XI Spinal accessory | General visceral efferent Special visceral efferent | Sternomastoid and trapezius, uvula, and levator veli palatini | Muscles of neck and shoulder (movement); soft palate (movement) |

THE CRANIAL NERVES—PART II (*Continued*)

| <i>Nerve</i> | <i>Functional Components</i> | <i>Structures Innervated by Afferent Fibers, and Sensation Mediated</i> | <i>Structures, Innervated by Efferent Fibers, and Reaction Initiated</i> |
|-----------------|--|---|--|
| XII Hypoglossal | General somatic efferent General somatic afferent | Muscles of tongue (muscle sense) | Muscles of tongue (movement) |

The following rhyme is widely used in memorizing the names and numerical sequence of these nerves: "On Old Olympus' Towering Tops A Finn And German Viewed Some 'Hops."

ESSENTIAL FACTS ABOUT THE CRANIAL NERVES. The accompanying tables summarize the essential facts relating to the cranial nerves. Such facts are: type (sensory, motor, or mixed), superficial origin, deep origin, exit from cranium, functional components, structures innervated by afferent fibers and sensation so mediated, and structures innervated by efferent fibers and reaction initiated.

SPECIAL PHENOMENA RELATING TO THE CRANIAL NERVES. The following special phenomena have been noted with relation to the cranial nerves:

1. All cranial nerves except I (olfactory) and II (optic) arise from the brain stem.

2. The olfactory tract and bulb and the optic nerve and tract are not true peripheral nerves (as are the other cranial nerves). Each develops as an evagination of the prosencephalon and is thus fundamentally comparable to a tract of the central nervous system. These nerves conduct only afferent (sensory) impulses.

3. Three of the cranial nerves are involved in the innervation of the musculature of the eyes (III, IV, and VI). Formerly these nerves were regarded as strictly motor, but it is now well established that the oculomotor nerve carries sensory proprioceptive impulses, and it is probable that the trochlear and abducens nerves also carry sensory impulses.

4. The trochlear nerve (IV) is the cranial nerve of smallest diameter; the trigeminal (V) is the largest.

5. The acoustic nerve (VIII) is the only cranial nerve that does not pass completely through the cranium. It terminates at the inner ear within the temporal bone.

6. The trigeminal nerve (V) is the principal sensory nerve of the superficial and deep portions of the head and face. It is also the motor nerve for the muscles of mastication.

7. The vagus nerve (X) has the most extensive distribution. Only three small branches (meningeal, auricular, and pharyngeal) reach structures in the head; the main portion of the nerve passes through the neck into the thorax, where branches pass to the larynx, trachea, bronchi, lungs, heart, and pericardium. Branches of the right and left vagus form branching networks of fibers about certain structures; these fibers constitute the *pulmonary*, *cardiac*, and *esophageal plexuses*. On passing through the diaphragm, the branches enter the stomach, liver, spleen, pancreas, kidney, small intestine, and ascending and transverse colon. Important plexuses are the *gastric*, the *splenic*, and the *celiac*.

8. Four of the cranial nerves (III, VII, IX, and X) carry fibers of the autonomic nervous system and constitute a part of the cranio-sacral (parasympathetic) division of that system.

Spinal Nerves. Thirty-one pairs of spinal nerves arise from the spinal cord. There are eight pairs of *cervical nerves*, twelve pairs of *thoracic nerves*, five pairs of *lumbar nerves*, five pairs of *sacral nerves*, and one pair of *coccygeal nerves*. The first cervical nerve emerges between the occipital bone and the atlas; all other emerge from the intervertebral foramina between adjoining vertebrae.

STRUCTURE AND ATTACHMENT OF SPINAL NERVES. Each spinal nerve is attached to the spinal cord by a posterior root and an anterior root. A short distance from the spinal cord, the roots unite to form the main trunk of the spinal nerve.

Roots of Spinal Nerves. On the *posterior (sensory afferent or dorsal) root* is found an ovoid mass of nerve cells, the *spinal ganglion*. Nerve fibers in this root have their origin in cells of this ganglion. The neurons of spinal ganglia are pseudo-unipolar. From each cell body emerges a single process, which bifurcates a short distance from the cell body. One branch, the *peripheral branch*, passes laterally toward the periphery; although it conveys impulses to the cell body and therefore is functionally a dendrite, structurally it possesses a myelin sheath and neurilemma and thus resembles an axon. For this reason, it is called an axon-like dendrite. The *central branch* passes into the spinal cord. The posterior root, on approaching the spinal cord, breaks up into a number of root-filaments, which pass through the dura mater and connect with the cord.

Each *anterior (motor efferent or ventral) root* consists of several root filaments which emerge from the anterior surface of the cord. These filaments are made up of efferent fibers (axons) of neurons whose cell bodies lie in the gray matter of the spinal cord.

Branches of Spinal Nerves. A typical spinal nerve, such as an intercostal nerve, passes through the intervertebral foramen and almost immediately divides into four branches. These branches are:

The *recurrent branch*, a small branch which turns medially and re-

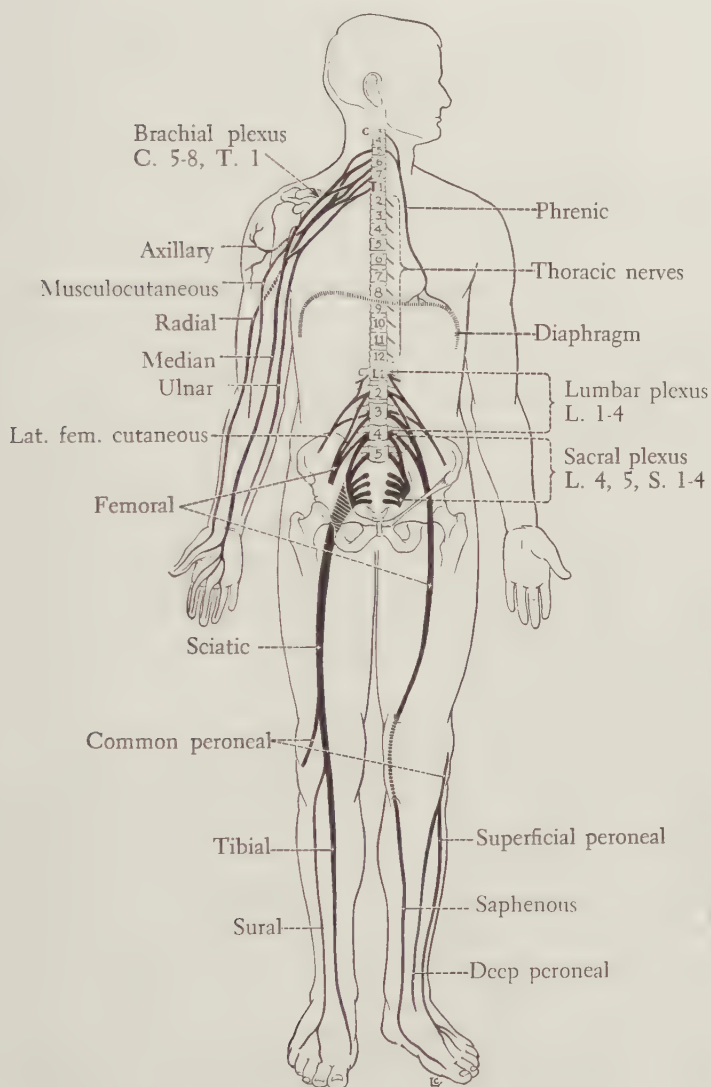


Fig. 4-11. Spinal cord and spinal nerves. The *pudendal plexus* is a downward continuation of the sacral plexus. The *coccygeal plexus* includes the 5th sacral nerve, the coccygeal nerves, and a branch of the 4th sacral nerve. (Reprinted with permission of W. B. Saunders Company from Millard, King, and Showers, *Human Anatomy and Physiology*, 4th ed., 1956.)

enters the vertebral canal. It innervates the meninges and vessels of the spinal cord.

The *dorsal ramus* or *posterior primary division*, which turns posteriorly and innervates the skin, muscles, and fascia of the back.

The *ventral ramus* or *anterior primary division*, which passes laterally and continues ventrally in the body wall. It divides into a *lateral cutaneous branch*, which innervates the skin, and an *anterior branch*, which innervates the muscles of the body wall and the linings of the body cavities. The latter terminates near the midline in an *anterior cutaneous branch*, which innervates the skin on the ventral surface of the body.

The *rami communicantes* (sing., *ramus communicans*), short, thread-like filaments passing ventrally from the anterior primary division (ventral ramus) and connecting it with the autonomic ganglia of the sympathetic trunk. These rami are of two types: the white ramus and the gray ramus. The *white ramus* is composed principally of myelinated axons whose cell bodies lie in the lateral horn of the gray matter of the cord (the neurons are called *preganglionic neurons*). These axons synapse with neurons in autonomic ganglia. The white ramus may also contain visceral afferent fibers, whose cell bodies lie in spinal ganglia. The *gray ramus* is made up of unmyelinated fibers (axons) of neurons (*postganglionic neurons*) whose cell bodies lie in autonomic ganglia, which fibers, on entering the anterior division of the spinal nerve, pass peripherally to smooth muscles and glands of the body wall or the extremities.

FUNCTIONAL COMPONENTS OF SPINAL NERVE. A typical spinal nerve contains the following functional components:

Afferent fibers, which may be either *general somatic afferent fibers* (fibers which conduct sensory impulses from exteroceptors or proprioceptors to the spinal cord) or *general visceral afferent fibers* (sensory fibers which conduct sensory impulses from enteroceptors to the spinal cord). The cell bodies of both types of fibers lie in the spinal ganglia.

Efferent fibers, which may be either *general somatic efferent fibers* (motor fibers which conduct impulses to striated muscles and whose cell bodies lie in the anterior column of the gray matter of the spinal cord) or *general visceral efferent fibers* (motor fibers which conduct motor and secretory impulses to smooth muscle, cardiac muscle, and glands). Impulses arise from *preganglionic neurons* (primary neurons) in the lateral horn of the gray matter of the cord and pass through the anterior root and white ramus to ganglia of the sympathetic trunk. At this point they synapse with *postganglionic neurons* (secondary neurons), whose axons may (a) pass to visceral organs through autonomic nerves, or (b) return to the anterior division of the spinal nerve through the gray ramus and pass to smooth muscles, espe-

cially those of blood vessels, and to glands located in the peripheral portions of the body.

Concerning spinal nerves in general, it is noted that:

1. The dorsal or posterior root contains only *afferent* fibers conducting impulses from the periphery to the spinal cord. Between the spinal ganglion and the cord, the dorsal root is composed of axons; between the ganglion and the trunk of the spinal nerve, it is composed of axon-like dendrites.

2. The ventral or anterior root contains only *efferent* fibers (axons), whose cell bodies lie in the gray matter of the spinal cord.

3. The main nerve trunk contains both *afferent and efferent* fibers (both axons and dendrites).

PLEXUSES OF SPINAL NERVES. In the thoracic region, the spinal nerves are arranged segmentally, each pair innervating a more or less specific segment of the body. In the other regions of the spinal cord, however, the ventral rami of the spinal nerves anastomose with adjacent spinal nerves, forming plexuses. These are the *cervical plexus*, the *brachial plexus*, the *lumbosacral plexus*, and the *coccygeal plexus*.

Cervical Plexus. This plexus, lying in the neck alongside the first four cervical vertebrae, is formed by an anastomosis of the ventral rami of the first four cervical nerves. From it *superficial* and *deep branches* go to the skin of the head, neck, and shoulder; to certain muscles (trapezius, sternocleidomastoid, levator scapulae, and scalenus medius); and one, the *phrenic nerve*, passes to the diaphragm. Communicating branches connect with cranial nerves X, XI, and XII and with the sympathetic trunk.

Brachial Plexus. This plexus is formed by the last four cervical nerves and the first thoracic nerve. The fifth and sixth cervical nerves join to form the *upper trunk*; the seventh forms the *middle trunk*; the eighth cervical and first thoracic join to form the *lower trunk*. The anterior divisions of the upper and middle trunks unite to form the *lateral cord*, while the anterior division of the lower trunk alone gives rise to the *medial cord*. Each of the posterior divisions from the three trunks combine to form the *posterior cord*. The branches of the cords constitute the nerve supply of the upper extremity. The principal branches of each cord are:

Lateral cord: musculocutaneous nerve and lateral root of median nerve.

Medial cord: ulnar nerve and medial root of the median nerve.

Posterior cord: axillary, radial, and subscapular nerves.

The *median nerve* extends along the medial side of the arm and forearm to the hand, with fibers extending to the fingers. Efferent fibers go to the muscles on the anterior side of the forearm, supplying in general the flexors and pronators. Afferent fibers supply the integu-

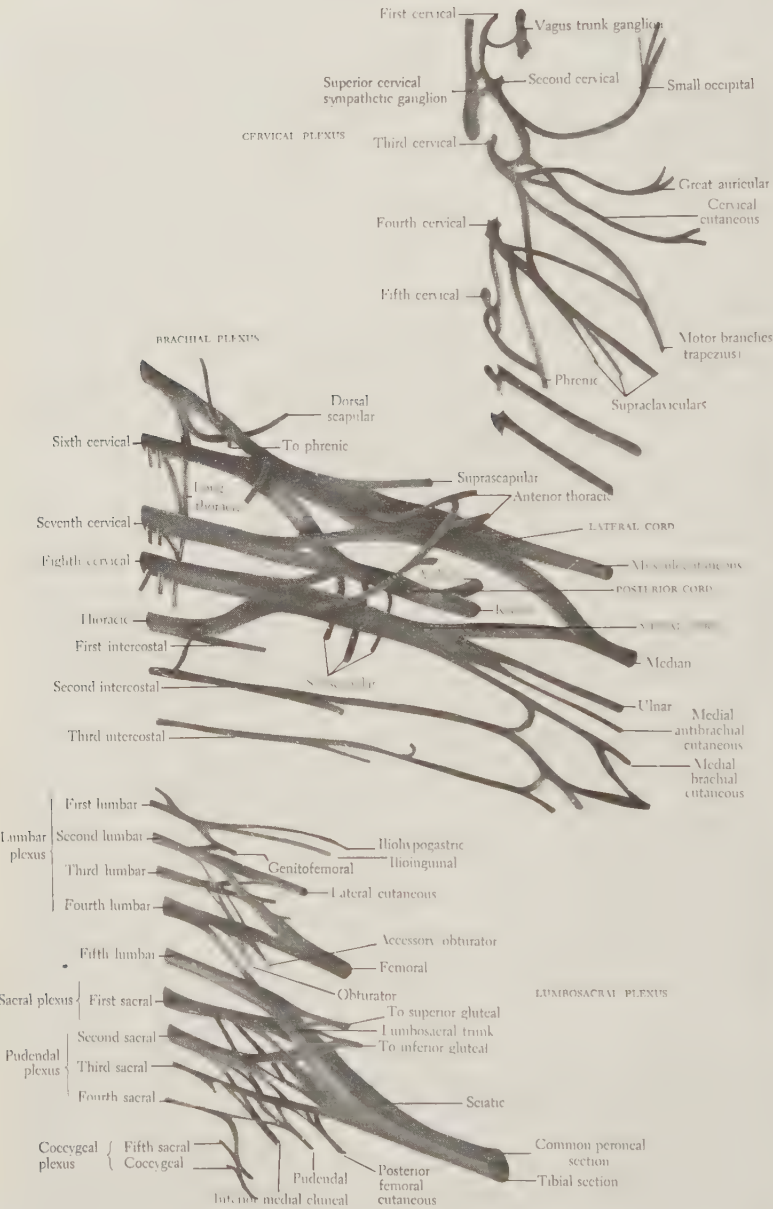


Fig. 4-12. Cervical, left brachial, and left lumbosacral plexuses.

ment covering the central portion of the palm and a portion of the ulnar eminence. The *musculocutaneous nerve* supplies the coracobrachialis, biceps brachii, and brachialis muscles; cutaneous branches go to the skin. The *ulnar nerve* lies along the medial side of the arm, sending branches to the elbow joint, forearm, and hand. The *axillary nerve* is the largest branch of the brachial plexus, containing fibers of the 5th, 6th, 7th, and 8th cervical nerves. It passes along the lateral side of the humerus to the region of the elbow, where it divides into *deep* and *superficial* branches which extend to the digits. It innervates the triceps brachii, brachioradialis, extensor carpi radialis, and a part of the brachialis muscles. Cutaneous branches receive sensory fibers from the skin on the posterior surface of the arm and hand. The *subscapular nerves* (upper, middle or thoracodorsal, and lower) are small nerves supplying the subscapularis, latissimus dorsi, and teres major muscles.

Between the brachial and the lumbosacral plexuses, twelve pairs of *thoracic* or *intercostal nerves* are given off from the spinal cord. They pass laterally in the intercostal spaces, supplying fibers to the muscles and skin of the thoracic and abdominal walls. There being no plexus formation, each nerve follows an independent pathway. The first two intercostal nerves contribute fibers through the brachial plexus to the upper limbs. The last five supply the skin and muscles of the abdominal wall. Each of the thoracic nerves is connected to a corresponding ganglion of the sympathetic trunk by two rami: a *white* and a *gray communicating ramus*.

Lumbosacral Plexus. This plexus is formed by the anterior rami of the lumbar, sacral, and coccygeal nerves. For convenience this plexus is divided, in this description, into three parts: the *lumbar*, the *sacral*, and the *puddendal plexuses*.

The *lumbar plexus* is formed by the anterior rami of the first three lumbar nerves and a part of the fourth. Branches from this plexus supply the muscles and skin of the lower abdominal wall and a part of the lower extremity. The principal branches of the lumbar plexus and their distribution are: *iliohypogastric*, to skin of gluteal and hypogastric regions; *ilioinguinal*, to muscles of upper and medial portions of the thigh and to external genitalia; *genitofemoral*, one branch to the scrotum (male) or the round ligament (female), another branch to skin of the upper anterior portion of the thigh; *lateral femoral cutaneous*, to skin on lateral side of thigh; *femoral*, the largest branch, formed by branches of the 2nd, 3rd, and 4th lumbar nerves and supplying muscles and skin of the anterior and medial sides of the thigh and leg (principal branches are *intermediate* and *medial cutaneous nerves* and *saphenous nerve*, whose branches extend as far as the foot, where they are primarily sensory); *obturator*, which passes through the

obturator foramen to the thigh, where it divides into *anterior* and *posterior branches* supplying the abductor muscles and the knee joint. In the thigh, branches of the saphenous nerve supply the quadriceps femoris muscle.

The *sacral plexus* is formed by branches of the 4th and 5th lumbar nerves and the 1st, 2nd, and 3rd sacral nerves. The nerves of this plexus unite to form a single flattened band, which passes through the *greater sciatic notch*, below which the band is known as the *sciatic nerve*.

The *sciatic nerve* is the largest single nerve in the body, measuring about 2 cm. in width. It passes along the posterior surface of the thigh, being crossed by the piriformis and biceps femoris muscles. In the region of the knee, it divides into two branches: the *tibial* and the *common peroneal*. These two branches actually retain their identity throughout the entire course of the sciatic nerve from its origin at the plexus. The tibial nerve passes along the posterior side of the leg, giving off articular, muscular, and cutaneous branches. The common peroneal nerve passes along the lateral surface of the leg, giving off similar branches.

Other branches of the sacral plexus are: the *superior* and *inferior gluteal nerves*, which supply motor fibers to the gluteal muscles and the tensor fascia latae; and the *posterior femoral cutaneous nerve*, which supplies the skin and the posterior surface of the thigh and leg. Nerves of this plexus also include (a) a nerve to the quadratus femoris, (b) one to the obturator internus, and (c) another to the piriformis muscle. The *pudendal plexus* is a downward continuation of the sacral plexus.

The *pudendal nerve*, the main branch of the pudendal plexus, consists of fibers from the 2nd, 3rd, and 4th sacral nerves. It gives off the following branches: *inferior (rectal) hemorrhoidal*, distributed to the lower end of the rectum and muscles and skin surrounding the anus; *perineal*, supplying the scrotum and proximal portion of the penis (the labia majora in the female); and *dorsal nerve of penis (clitoris in female)*, supplying dorsal and distal portions of external genitalia.

Coccygeal Plexus. This plexus is sometimes considered a subdivision of the pudendal plexus. It consists of the 5th sacral and the *coccygeal nerves*, with a branch of the 4th sacral nerve. It supplies the skin in the region of the coccyx.

THE AUTONOMIC NERVOUS SYSTEM

There is a lack of uniformity in the terminology applied to that part of the nervous system which innervates the viscera. It has been variously referred to as the *visceral motor system*, *involuntary nervous system*, and *vegetative nervous system*. The term "autonomic nervous

system" has come into more or less general use because it signifies a *functional* unit which may be conveniently studied, rather than an anatomic division.

General Description. The autonomic nervous system includes those structures which are concerned with innervation of smooth muscles, glands, and cardiac muscle. It comprises nerves, ganglia, and plexuses. In general, it innervates structures the activities of which are essential for the life of the organism, those which are involuntary and automatic. It supplies the digestive, respiratory, urinary, reproductive, circulatory, and endocrine systems—that is, all effector organs of the body with the exception of striated muscles. Examples of activities controlled by this system are: accommodation for near vision, changes in size of the pupil, constriction and dilatation of blood vessels, rate and force of heart beat, muscular activities of the digestive tract, emptying of the urinary bladder and gallbladder, erection of the penis, occurrence of gooseflesh, and secretion by all glands under nervous control.

The autonomic nervous system is *entirely motor*; that is, it includes only efferent fibers which carry impulses to specific tissues (muscle or gland), either increasing or decreasing their activity. The nerve fibers are arranged in two opposed systems, both of which (with a few exceptions) supply a single structure. These two divisions are the *craniosacral* or *parasympathetic* and the *thoracolumbar* or *sympathetic*.

From the preceding paragraph it might be inferred that there are no afferent impulses from the visceral organs. Such is not the case; there do exist nerve fibers which conduct afferent impulses (for example, pain impulses originating in the intestine). However, these fibers are the peripheral processes of sensory cells lying in the spinal ganglia; consequently, they belong to neurons which are not a part of the autonomic nervous system.

Visceral Efferent Neurons. In the autonomic nervous system, at least two neurons are always involved in the conduction of impulses from the cord or the brain to an effector organ. These neurons are known as *preganglionic* and *postganglionic neurons*.

PREGANGLIONIC NEURONS. The cell bodies of preganglionic neurons also designated as "first-order neurons," lie in the central nervous system (the brain and the spinal cord). Their axons (called *preganglionic fibers*) pass through cranial or spinal nerves to ganglia, where they terminate. They are myelinated or white fibers.

POSTGANGLIONIC NEURONS. The cell bodies of postganglionic neurons, also designated as "second-order neurons," lie in the ganglia located outside the central nervous system. Their unmyelinated axons (called *postganglionic fibers*) terminate in smooth muscles, the heart, or glandular tissue. The visceral structures which they innervate are widely distributed, being found in nearly all portions of the body.

Postganglionic fibers reach these structures in two ways: (1) *Through craniospinal nerves*. Visceral structures lying in somatic regions, such as cutaneous blood vessels and sweat glands, receive their fibers through the medium of craniospinal nerves. These fibers, which are unmyelinated, have their origin in cells lying in autonomic ganglia. (2) *Through visceral autonomic nerves*. Visceral structures lying in the thorax, abdomen, and head receive autonomic fibers through the medium of autonomic nerves. These nerves usually follow the artery which supplies blood to the organ innervated.

Ganglia of the Autonomic Nervous System. Three types of ganglia are present in the autonomic nervous system. They are: *vertebral or lateral, prevertebral or collateral, and terminal or intramural ganglia*.

VERTEBRAL (LATERAL) GANGLIA. These ganglia lie in linear order on either side of the vertebral column close to the bodies of the vertebrae. They are united, forming a chain or trunk, the *sympathetic trunk*, which extends from the base of the skull to the coccyx. There are twenty-two ganglia in each trunk, the most superior comprising the *superior, middle, and inferior cervical ganglia*. The latter is frequently fused with the first thoracic ganglion to form the *stellate ganglion*.

PREVERTEBRAL (COLLATERAL) GANGLIA. These ganglia lie in the thorax, abdomen, and pelvis, near the aorta or branches of it. Important prevertebral ganglia are the *celiac, superior mesenteric, and inferior mesenteric*. They are found near the bases of the arteries after which they are named.

TERMINAL (INTRAMURAL) GANGLIA. These ganglia lie close to, or within, the structures which their fibers innervate. In the *head* region, the ciliary, sphenopalatine, submaxillary, and otic ganglia contain the cell bodies of neurons which give rise to postganglionic fibers innervating the eyes, lacrimal glands, salivary glands, and mucous membrane of the mouth and pharynx. In the *thorax* and *abdomen*, terminal ganglia are present in the form of plexuses found close to, or within, the visceral organs. Examples of these are cardiac ganglia and *Auerbach's* and *Meissner's* plexuses in the intestine.

Divisions of the Autonomic Nervous System. Anatomically and functionally, the autonomic system can be divided into the *parasympathetic* and the *sympathetic divisions*. These are also known as the *craniosacral* and *thoracolumbar* divisions, respectively. These two divisions, in general, have antagonistic effects on the organs they innervate. One acts to initiate or increase activity, the other to inhibit or slow it down. This rule does not apply to each division as a whole, but to the individual organs or structures.

COMPARISON OF THE TWO DIVISIONS. The two divisions of the autonomic system differ in the following respects:

1. In general, visceral effector organs have a double innervation; that is, they are innervated by efferent fibers from both divisions.* Impulses carried by the fibers of one division are antagonistic to those of the other. For example, impulses to the heart through the parasympathetic division slow down or inhibit the heart beat, whereas impulses through the sympathetic division speed up the heart beat.

2. Efferent fibers of the first-order neurons of the parasympathetic division terminate in terminal ganglia, where they synapse with second-order neurons; efferent fibers of the sympathetic division terminate in lateral or collateral ganglia.

3. At the termination of efferent neurons in effector organs, different chemical substances are produced. *Acetylcholine* is produced at parasympathetic endings, *norepinephrine* at sympathetic endings (with a few exceptions).

4. The two divisions differ in their responses to certain specific drugs. Some drugs affect the fibers of the parasympathetic division; others affect only those of the sympathetic division.

PARASYMPATHETIC (CRANIOSACRAL) DIVISION. In this division the first-order neurons (preganglionic neurons), which send efferent fibers to the visceral organs, lie in the brain stem or in the sacral region of the spinal cord. Their fibers (axons) pass through four cranial nerves (III, VII, IX, and X) or three sacral nerves (2nd, 3rd, and 4th) to the visceral structures which they innervate. They end in terminal ganglia, where they synapse with second-order neurons (postganglionic neurons).

The parasympathetic division exercises its effects principally during periods of rest, when restorative processes are being brought into play and energy supplies are being replenished. In general, parasympathetic effects are *specific*; that is, they tend to involve individual organs rather than the organism as a whole. Some of the parasympathetic effects are: (*a*) slowing of heart beat, (*b*) storage of glycogen by the liver, (*c*) increased tone and motility of the intestine, (*d*) constriction of bronchioles (especially in the presence of noxious stimuli), and (*e*) constriction of the pupils of the eyes.

SYMPATHETIC (THORACOLUMBAR) DIVISION. In this division the first-order neurons (preganglionic) lie in the gray matter of the spinal cord in the thoracic and lumbar regions. Their fibers (axons) pass through the anterior roots and white rami of thoracic and lumbar spinal nerves to vertebral or prevertebral ganglia, where they synapse with second-order neurons (postganglionic).

The sympathetic division acts rapidly to bring about generalized

* A few visceral structures, namely, the sweat glands, erector muscles of hair follicles, and blood vessels of the digestive tract, apparently receive fibers only from the sympathetic division.

changes in the functioning of those organs that facilitate the quick mobilization and release of energy. Such changes are required under emergency conditions (those involved in activities associated with fright, fighting, pain, fear, or anger). Some of the sympathetic effects noted under such conditions are: (a) increase in blood pressure accompanied by accelerated heart beat, increased force of heart beat, contraction of arterioles (especially in skin and in visceral organs), and dilatation of coronary arteries and arteries going to skeletal muscles; (b) increase in blood sugar resulting from glycogen breakdown in the liver; (c) increased volume of blood resulting from splenic contractions; (d) dilatation of bronchi, increasing oxygen intake; and (e) dilatation of the pupil. It will be seen that the foregoing changes enable the body to adapt itself to sudden emergencies which involve intense muscular activity or accompany emotional excitement in anticipation of such activity. In general, sympathetic effects are widespread, involving many organs or the body as a whole.

IMBALANCE BETWEEN THE TWO DIVISIONS. Normally, the parasympathetic and sympathetic divisions are in balance, the activity of one or the other coming into dominance according to the needs of the organism. In some individuals, there may be a marked shift toward one or the other, resulting in an imbalance, with corresponding functional disorders. The influence of emotional states on this delicate balance of the autonomic nervous system is a matter of common observation. When the parasympathetic division tends to dominate, the condition is called *parasympathicotonia*; when the sympathetic division dominates, the condition is called *sympathicotonia*.

Functions of the Autonomic Nervous System. The autonomic nervous system regulates the activities of the visceral organs, which are essential to the existence of the organism and to its reproduction. These activities are involuntary; that is, they are not susceptible to conscious control. Among the organs under autonomic control are heart and blood vessels, respiratory organs, alimentary canal, kidneys and urinary bladder, reproductive organs, and endocrine glands.

• Visceral organs normally function automatically if they are provided with the necessary materials and protected from environmental changes. When conditions occur which alter the physiological requirements of the organism, the visceral organs may need to function at an increased or decreased rate to meet the situation. The autonomic system provides the mechanism by which such activities are regulated.

Some of the effects produced by the two divisions of this system are summarized in the table on page 125. It will be noted that, in general, the impulses from one division are antagonistic to those of the other.

MAINTENANCE OF BALANCE IN BODY FLUIDS. The functions of the autonomic nervous system are directed toward maintaining a constant,

EFFECTS OF AUTONOMIC STIMULATION

| EFFECTOR ORGAN | CRANIAL-SACRAL OUTFLOW (<i>Parasympathetic Division</i>) | THORACOLUMBAR OUTFLOW (<i>Sympathetic Division</i>) |
|--------------------------|---|--|
| <i>Muscles</i> | | |
| Iris | Contraction of circular fibers; constriction of pupil | Contraction of radial fibers; dilation of pupil |
| Ciliary | Contraction in accommodation (lens becomes convex) | None |
| Of blood vessels (skin) | Vasodilation | Vasoconstriction |
| Cardiac | Inhibition (heart rate slowed) | Stimulation (heart rate accelerated) |
| Of bronchi | Constriction | Dilation |
| Of digestive tract | | |
| (a) in the wall | Contraction (stimulates peristalsis) | Relaxation (inhibits peristalsis) |
| (b) sphincters | Relaxation | Contraction |
| Of urinary bladder | | |
| (a) bladder wall | Contraction (induces micturition) | Inhibition |
| (b) sphincters | Relaxation | Contraction (retention of urine) |
| Of uterus (in pregnancy) | Inhibition | Contraction |
| Of hair follicles | None | Contraction (erection of hairs) |
| <i>Glands</i> | | |
| Salivary glands | Stimulates serous-secreting cells | Stimulates mucous-secreting cells |
| Digestive glands | Stimulates secretion | Inhibits secretion |
| Sweat glands | None | Stimulates secretion |

balanced internal environment (*homeostasis*). Within the body, changes are continuously taking place in many areas, where body fluids tend to become altered in chemical composition, temperature, and distribution. The autonomic nervous system acts to regulate such activities in order to prevent excesses. Through its regulation of the *heart* and of the caliber of *blood vessels*, the flow of blood to the various parts of the body is controlled. Through its regulation of smooth muscle, the size of tubes or openings and diameter of vessels are controlled. Through its regulation of certain *viscera*, enzymes are produced and food is moved through the alimentary canal to facilitate digestion and absorption of energy-producing materials. Through its regulation of the *urinary organs*, waste products are eliminated from the body. Through its regulation of the sweat glands and other organs, *constant temperature* is maintained. Through its regulation of such organs as the pancreas, adrenal glands, and liver, all of which work together, the blood sugar level is maintained. Through its regulation of the endocrine glands and

their production of hormones, many functional activities are controlled. It can be seen, then, that (1) the body acts to maintain a uniformity of the body fluids which constitute the internal environment of the tissue cells, and (2) this uniformity is dependent upon the proper functioning of the parasympathetic and sympathetic divisions of the autonomic nervous system.

CONTROL OVER THE AUTONOMIC NERVOUS SYSTEM. In spite of the picture of widespread regulation of many activities by the autonomic nervous system that has been given in the preceding paragraph, it should be understood that this system does not operate separately and independently of the central nervous system. Control is exercised over it by centers in the brain, in particular the cerebral cortex, the hypothalamus, and the medulla oblongata. Although the autonomic nervous system carries out the functions in more direct relation to the affected areas, all body functions are regulated and coordinated through these higher mechanisms.

FUNCTIONAL LEVELS. Activities that are under the control of the autonomic nervous system occur at various functional levels. For example, *peristaltic movements* of the intestine take place even when segments of the intestine are removed from the body. Such movements presumably are the result of local (intramural) reflexes, although the afferent fibers involved have not been definitely identified. *Micturition* occurs reflexly from connections between afferent and efferent fibers in the same segment in the lower region of the spinal cord. Certain reflexes involving parts of the *digestive tract* are brought about by intersegmental connections in the upper portions of the spinal cord. *Respiratory* and *circulatory* reflexes have their centers in the lower portion of the brain stem (medulla oblongata). Temperature is controlled through reflex centers in the hypothalamus. *Cortical* activities may be accompanied by specific autonomic effects. Examples of the last are: increased rate of heart beat, rise in blood pressure, pallor of the skin resulting from fright, sweating of the palms resulting from mental agitation, salivary and gastric secretion resulting from the thought of food, and nausea and vomiting from witnessing an unpleasant sight.

The Autonomic Reflex Arc. The activities under autonomic control are almost entirely reflex in nature. A stimulus initiates an impulse in an afferent neuron, which is transmitted through the nervous system to the visceral effector organ or organs, bringing about a response. The parts involved in such a reflex are:

1. A *receptor*, either somatic or visceral.
2. An *afferent neuron* (somatic or visceral), which conducts the impulse to the spinal cord or brain, where it synapses with an *inter-nuncial neuron*.

3. An *internuncial neuron* lying within the spinal cord or brain; this neuron synapses with a visceral efferent neuron.

4. A *visceral efferent preganglionic neuron*. In the thoracic and abdominal regions, this neuron lies in the lateral horn of the gray matter of the cord. Its axon passes through the anterior root and white ramus of a spinal nerve to vertebral or prevertebral ganglia, where it synapses with postganglionic neurons. In the cranial and sacral regions, its axon passes to terminal ganglia, where it synapses with postganglionic neurons.

5. A *visceral efferent postganglionic neuron* (effector neuron), which transmits the impulse to an effector organ.

6. An *effector organ* (smooth muscle, cardiac muscle, or gland).

The autonomic reflex arc differs from that of the craniospinal system in that two *efferent neurons* are always involved, and the cell body of the second or effector neuron lies outside the central nervous system.

Humoral or Chemical Transmission of Impulses. Nerve fibers leading to muscle or glandular tissue come into intimate relationship with only a few of the cells comprising the structure, yet nerve impulses to an effector organ bring about either excitation or inhibition of most or all the cells of that structure. It has been determined that such effects are induced by specific chemical substances elaborated at the nerve endings. These substances, called *neurohumors* or *neurotransmitters* (*transmitting agents*), are *acetylcholine* and *norepinephrine*.

ACETYLCHOLINE. This substance is produced at the endings of the postganglionic fibers of the parasympathetic (craniosacral) division—for example, at the vagus nerve endings in the heart. It is also produced at the motor end-plates in skeletal muscles and in ganglia at all synapses between preganglionic and postganglionic neurons. Any fiber that liberates acetylcholine is said to be a *cholinergic fiber*. Acetylcholine, after its production, is quickly destroyed or inactivated by an enzyme, *cholinesterase*, present in the tissues.

NOREPINEPHRINE. It was formerly thought that a substance called *sympathin* was liberated at the endings of postganglionic fibers of the sympathetic (thoracolumbar) division. However it has been established that this transmitter agent is a hormone, *norepinephrine*, which is also secreted by the adrenal medulla. Norepinephrine in its effects resembles epinephrine in that both increase systolic and mean arterial blood pressure. Norepinephrine is a vasoconstrictor acting especially on peripheral blood vessels; it has little effect on the heart. Its effect on smooth muscle, like that of epinephrine, may be one of excitation or inhibition depending on the organ and its physiological state. Epinephrine also is secreted at sympathetic endings but in very small amounts.

Fibers which produce norepinephrine as a transmitter agent are called *adrenergic fibers*. All sympathetic postganglionic fibers are

adrenergic except those supplying the sweat glands and uterus. Nor-epinephrine is rapidly inactivated in the tissues by oxidation or esterification. The exact mechanism by which this is accomplished is not known at the present.

Effects of Drugs on the Autonomic Nervous System. Certain drugs are known to have specific effects on organs enervated by the autonomic nervous system. Some affect those receiving parasympathetic fibers; others affect those receiving sympathetic fibers.

EFFECTS ON PARASYMPATHETIC EFFECTOR ORGANS. The following drugs have been shown to have these effects:

1. *Atropine* acts to inhibit craniosacral effects; consequently, it dilates the pupil, dilates the bronchioles, reduces secretion by mucous membranes of the respiratory passageways, and inhibits movements of the alimentary canal.

2. *Pilocarpine*, *muscarine*, and *physostigmine* act to stimulate craniosacral effects, an action antagonistic to that of atropine.

EFFECTS ON SYMPATHETIC EFFECTOR ORGANS. The following drugs have been shown to have these effects:

1. *Epinephrine* (*adrenalin*) is secreted by the medulla of the adrenal gland. It produces the same effects as does stimulation of the thoracolumbar division. Adrenalin is used in the treatment of shock because it stimulates the heart and constricts the arterioles. In the treatment of asthma, it relaxes the bronchioles. In hypoglycemia, it stimulates the liver, bringing about the breakdown of glycogen and liberation of glucose into the blood stream. It also causes more rapid clotting of blood; this, in conjunction with constriction of the arterioles, tends to decrease loss of blood from injury. Used in combination with certain local anesthetics, epinephrine tends to decrease the rate of absorption and thus prolong the anesthesia.

2. *Ephedrine*, an alkaloid derived from a plant, produces effects similar to those of epinephrine, except that they are less powerful but more prolonged. It may be given orally, whereas epinephrine must be given by injection.

3. *Ergotoxin* inhibits motor effects of the sympathetic division. It is antagonistic to epinephrine.

VISCERAL AFFERENT FIBERS AND VISCERAL SENSATIONS

Receptors are present in most or all visceral organs. These are the endings of visceral afferent fibers whose cell bodies lie in the ganglia of cranial and spinal nerves. These fibers pass in the same trunks along with autonomic fibers but they are not considered a part of the auto-

onomic system, for this division consists only of efferent fibers passing from the central nervous system.

In the brain, visceral impulses may or may not reach cortical or conscious levels. Most remain at subconscious levels. At the conscious level, afferent fibers in the sympathetic nerves are involved mainly in the conduction of pain impulses; those in the parasympathetic nerves are concerned with the conduction of impulses giving rise to sensations of hunger, nausea, fullness of the bladder and rectum, and similar sensations.

Visceral sensations differ from somatic sensations in that they are generally vague and poorly localized. When the abdominal cavity is opened under local anesthesia, visceral organs can be handled, cut, or even burned without producing sensations of touch or pain. At times, however, pain does occur in the form of cramps, a severe ache, or colic. The stimuli giving rise to these sensations are: overdistention of a viscus as from overeating or from swallowing air; obstruction of a tube (e.g., obstruction due to calculi in the biliary or urethral passageways); excessive contraction or spasm of smooth muscle; pathologic or inflammatory conditions as in appendicitis, and ischemia.

Normally, activities of visceral organs do not arouse conscious sensations; that is, one is not aware of peristaltic contractions of the intestine, the heart beat, or changes in the diameter of blood vessels. This is probably because such activities are not of sufficient intensity to initiate impulses in sensory receptors. However, accentuated activity of an organ, such as extremely rapid or forceful heart beat, may be registered in consciousness. The occurrence of visceral pain is generally regarded as a danger signal indicative of malfunctioning of some internal organ.

Afferent impulses are constantly arising in the viscera which do not reach the conscious levels. These are of importance in the reflex control of visceral activities. The visceral afferent fibers form the first part of a reflex arc by which impulses are conducted to reflex centers in the spinal cord and brain. Among such centers are the cardiac, respiratory, vasomotor, swallowing, and vomiting centers located in the medulla and the temperature control center in the hypothalamus.

5: SENSATIONS, SENSE ORGANS

The sense organs and sensory receptors and the sensations which they mediate constitute the means by which the organism is made acquainted with its environment, both internal and external.

THE NATURE OF SENSATIONS

A sensation is a state of awareness of conditions that prevail within or outside the body, or of changes in these conditions. There are four prerequisites for a sensation:

1. A stimulus capable of initiating a response by some part of the nervous system.
2. A receptor or sense organ which can react to the stimulus.
3. A pathway for conducting the impulse arising in the sense organ to the brain.
4. A region within the brain capable of translating the impulses into sensations.

Consciousness of Sensation. In the cerebral cortex and to some extent the thalamus and hypothalamus, the impulses arising in the sense organs bring about specific "feelings" or sensations. These sensations are the *conscious results* of the processes that occur within the brain as a consequence of impulses received from receptors. When one is awake, the cerebral cortex is constantly receiving countless numbers of afferent impulses. Some of them register in consciousness; others do not. A person can, within limits, select those stimuli which he wishes to register in consciousness (for example, he can listen to certain sounds and disregard others). This is the basis of *attention* and *concentration*. Some sensations persist within the brain and are susceptible of being recalled to consciousness at a later time. This is the basis of *memory*.

Projection of Sensations. Sensations have their basis in cortical activity within the brain. One sees, hears, or suffers pain *in the brain*. This may seem contrary to personal experience, since when a part of the body is injured it strikes one that the pain is localized in the injured part. Such a phenomenon is accounted for by the process called *projection*; the brain "projects" or refers the sensation to the point of stimulation or to the point of origin of the stimulus, which, in the case of auditory and visual sensations, may be outside the body. That the phenomenon is entirely mental is proved by the fact that when

cortical activity ceases, as in sleep, hypnosis, or anesthesia, the ability to form and to project sensations is lost.

Classification of Sensations. Sensations are commonly classified as *exteroceptive*, *interoceptive*, or *proprioceptive*.

EXTEROCEPTIVE SENSATIONS. These sensations give information about the external environment. They arise from stimuli outside the body and include the sensations of touch, pressure, temperature, pain, hearing, and sight. The sense organs that mediate these sensations are called *exteroceptors*, which may be further subdivided into *contact receptors* (the stimulus comes into direct contact with the sense organ) and *distance receptors* (the stimulus is of more or less remote origin).

INTEROCEPTIVE SENSATIONS. These sensations give information about the internal environment. They arise from stimuli within the body, the receptors being located principally in visceral organs. The sensations include pain, taste, and a number of indefinite sensations, such as fatigue, hunger, thirst, nausea, and suffocation, whose receptors have not been definitely identified. The sense organs that mediate these sensations are called *interoceptors*.

PROPRIOCEPTIVE SENSATIONS. These sensations give information about body position and movement. They include the kinesthetic senses (muscle-tendon sense, joint sense) and the sense of equilibrium. The sense organs that mediate these sensations are called *proprioceptors*.

Modalities of Sensations. Sensations have distinct characteristics by means of which one sensation can be distinguished from another. The combinations of these characteristics which constitute a sensation are referred to as *sensory modalities*. Sensory modalities depend on (a) the nature of the receptor or sense organ and (b) the nature of the region of the brain where the afferent fibers terminate.

NATURE OF THE RECEPTOR OR SENSE ORGAN. Sense organs tend to be specific and to respond to a particular type of stimulus. For example, the eye normally responds to light rays, but it may also respond to other types of stimuli, such as pressure or electric shock. Regardless of the type of stimulus, however, the modality of a sense organ is always fixed; that is, stimulation of a sense organ gives rise to sensations specific for that organ. This leads to the conclusion that all nerve impulses are alike in their fundamental nature; a nerve has no influence in determining the sensation or the response resulting from a stimulus. A *sensation* is determined primarily by the nature of the sense organ stimulated; the *response* is determined by the nature of the effector to which the impulse is conducted.

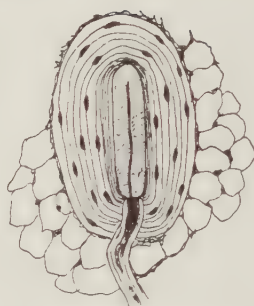
NATURE OF THE REGION OF THE BRAIN WHERE AFFERENT FIBERS TERMINATE. In some as yet unknown way the various sensory areas of



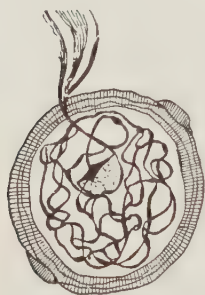
Free nerve endings
(pain)



Meissner's corpuscle
(tactile)



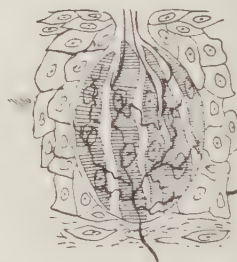
Pacinian corpuscle
(pressure)



End bulb of Krause
(cold)



Ruffini's end organ
(heat)



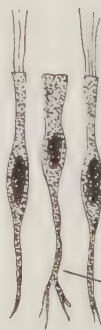
Taste bud



Receptor end organ
on a tendon
(proprioceptive)



Golgi-Mazzoni
corpuscle
(proprioceptive)



Cells from olfactory
mucous membrane



Nerve basket of
hair follicle

Supporting cell

Fig. 5-1. Receptors. (Reprinted with permission of The Macmillan Company from Kimber, et al., *A Textbook of Anatomy and Physiology*, 13th ed., 1955.)

the cerebral cortex have the ability to transform sensory impulses into specific sensations. For example, the visual center in the occipital lobe is able to produce a mental "picture" of the objects we see, a picture which in many cases can be recalled at will. A lesion of this portion of the brain may produce blindness even though all the other parts of the receptor and the afferent pathways have retained their normal function.

THE MODALITIES. The sensations of a given modality may differ in quality, intensity, duration, and adaptation.

Quality. Examples of quality are the colors of the light spectrum and the pitch of sound. Individual ability to distinguish between the qualities of a sensation is variable. Some persons can recognize extremely slight variations in pitch, whereas others are unable to discriminate between even the most obvious variations.

Intensity. A light may be bright or dim; a sound may be loud or faint. In general, the stronger the stimulus the greater the sensation. But an increase in the strength of a stimulus does not increase the intensity of the impulse that is carried over the nerve fiber; it is the *frequency of the nerve impulses* that is increased. In 1834 Ernst Heinrich Weber found that if a certain difference between the intensities of two stimuli was sufficient to be noted, the difference between two other intensities of the same stimulus must be proportionately as great in order to be noted. This is known as *Weber's Law*. For example, if a weight of 30 gm. is held in the hand and it requires the addition of 1 gm. (or one-thirtieth of the original weight) to produce a noticeable sensation of increase in weight, then with 60 gm. in the hand, a similar proportional increase in weight (that is, 2 gm.) would be required to produce a similar sensation. This law applies in general only to stimuli within median ranges of intensity.

Duration. Every sensation lasts a definite length of time. At times the duration is approximately the same as the duration of the stimulus; at other times the sensation may persist after the stimulus has been withdrawn (as when a sensation of light remains for a short period after a light has been turned off).

The persistence of a visual sensation is called an *after-image*. If one looks at the spokes of a slowly rotating wheel, he may be able to distinguish the individual spokes. If the speed of rotation is increased slowly, the images of the individual spokes tend to become blurred and to blend with one another. This occurs because the after-image of each spoke has persisted until the sensation of the next spoke is perceived. But if the rotation is very rapid, the wheel appears to be a solid structure. Similarly, if a number of slightly varying pictures are seen in rapid succession, the after-image of each carries over to the next so that the sensation is that of one continuous picture rather than of a number

of individual pictures. This is of course the principle underlying motion pictures.

Let us turn now to the sensation of touch. If one *feels* the spokes of a rotating wheel, each spoke will be felt regardless of whether the wheel is rotating slowly or rapidly. The after-image of the sensation of touch is of such short duration that it disappears before the next impulse is felt; consequently, there is no blending effect.

Adaptation. In some cases a sensation may disappear while the stimulus is still being applied. This phenomenon is called *adaptation*. If a hair is disturbed, a sensation is noted immediately, but this sensation disappears quickly. Similarly, if a ring is placed on the finger, its presence is quite noticeable at first, but gradually the sensation vanishes although the stimulus continues for days, weeks, or even much longer. Obnoxious odors may pass unnoticed after a time; deodorant purveyors are constantly reminding the buying public that a person is rarely conscious of his own body odor.

Proprioceptive or muscle-sense receptors show little propensity for adaptation, and pain sensations (such as those arising from cinder in the eye) show little or no tendency to adapt. In general, however, the nervous system does "adapt"; that is, it tends to ignore impulses arising from stimuli that are not harmful to the body, but harmful or noxious stimuli continue to produce unpleasant sensations. This tendency of the nervous system serves to make the body react by withdrawing from, eliminating, or adjusting to the offending stimulus.

CUTANEOUS SENSATIONS

(Sensory Impressions from the Skin)

Stimulation of the skin plays a much more important role in the development and maintenance of the health of the organism than has been generally recognized. The "licking" which domestic animals give their young is apparently necessary to stimulate the development of the gastrointestinal and genitourinary tracts of the young. Experiments have shown that when the young are prevented from being licked by their mothers (or any other animal) they frequently die of failure of function of the gastrointestinal and genitourinary tracts. The normal licking is responsible for initiating sensory impulses which pass to the central nervous system and are there mediated to the autonomic, from which motor impulses pass to the viscera.

It has long been known that when the new-born fails to breathe, giving it a few hearty slaps or skin massage will usually initiate breathing. This suggests that there is a connection between skin stimulation and the respiratory center. The reaction under a sudden cold shower of water similarly suggests such a connection.

It is also known that the breast-fed baby rarely suffers from gastro-

intestinal disorders as compared with the bottle-fed baby. The perioral stimulation associated with breast feeding seems to confer many physiological benefits upon the young. Similarly, it has been noted that there are significant physiological and physical differences between nursing and bucket-fed calves, the differences being appreciably in favor of the breast-fed animals.

In man, there is considerable evidence that a relation exists between skin stimulation and the development of the life-sustaining systems of the body.

The sensations mediated by the cutaneous sense organs or receptors are touch, pressure, cold, and heat. (Pain must also be included, but, inasmuch as the sphere of pain sensations transcends the cutaneous field, pain is more fully described under a separate heading, beginning on page 138.)

CUTANEOUS SENSATIONS AND THEIR SENSE ORGANS

| <i>Sensation</i> | <i>Sense Organ</i> | <i>Approx. Number of Points in the Skin</i> |
|-------------------------|--|---|
| Touch or light pressure | Merkel's tactile discs Meissner's corpuscles Hair root plexuses Nonencapsulated glomeruli | ? |
| Deep pressure | Pacinian corpuscles Corpuscle of Herbst | 500,000 |
| Cold | End bulbs of Krause | 150,000 |
| Heat | End organs of Ruffini | 16,000 |
| Pain | Naked nerve endings | 3 to 4 million |

Cutaneous Receptors. The foregoing receptors have a *punctiform* arrangement in the skin; that is, certain points when stimulated produce the sensation of pain, others of cold, others of pressure, and so forth. The fact that their distribution over the body surface is not uniform accounts for the considerable variation in the sensitiveness of different parts of the body. This has been shown in the "two-point special discrimination test," in which the subject is tested for ability to distinguish touch sensations coming from two points of a compass. This test shows the following order of sensitiveness (from greatest to least): tip of tongue, tip of finger, side of nose, back of head, and back of neck. Where the receptors are most numerous, sensitivity is greatest.

Cutaneous receptors are of two classes: (*a*) free or naked nerve endings, and (*b*) encapsulated nerve endings.

FREE OR NAKED NERVE ENDINGS. These consist of nonmyelinated sensory fibers which divide repeatedly and end in extremely fine

branches distributed among the epithelial cells. At the ends of the fibers are small knobs or expansions which may lie within or between the epithelial cells. When stimulated, these endings give rise to the sensation of pain.

Free nerve endings are not only found in the epidermis, where they are extremely abundant, but are also widely distributed in other tissues. They are present in the dermis of the skin, in mucous and serous membranes, in the cornea of the eye, in visceral organs, in the meninges, and in the pulp of teeth. They are stimulated by nearly all types of stimuli, although in the viscera stretching or distension is the primary stimulus.

Among these endings are Merkel's (tactile) discs, nonencapsulated glomeruli, and hair-root plexuses.

Merkel's (Tactile) Discs. Some nerve fibers end in a tiny expanded disc which lies in close contact with an epithelial cell. These structures, known as Merkel's discs or tactile discs, function as touch receptors in the epidermis. A single fiber may supply many discs.

Nonencapsulated Glomeruli. Some nerve fibers may end in an expanded structure that is spherical or elongated in shape. These nerve fibers, called nonencapsulated glomeruli, are found in the dermis and in the connective tissue underlying epithelial membranes. They are touch receptors.

Hair-Root Plexuses. Around the roots of hairs are found elaborate plexuses of nerve fibers ending in contact with the sheaths of the hair roots. Movement of the shaft of a hair produces a slight pressure on these endings which gives rise to the sensation of hair movement or touch.

ENCAPSULATED NERVE ENDINGS. These structures have nerve endings surrounded by a specialized capsule of connective tissue. The capsule is usually laminated. In it are cells and fluid-filled spaces.

Among these endings are corpuscles of Vater-Pacini (Pacinian corpuscles), end bulbs of Krause (Golgi-Mann corpuscles), end organs of Ruffini, and corpuscles of Meissner.

PACINIAN CORPUSCLES. These large structures (1 to 4 mm. in length) are found in the dermis and the subcutaneous layers of the skin, under mucous membranes, in mesenterics, in the pancreas, and in connective tissue in general. They mediate the sense of deep pressure. In the skin of the external genitalia and around the nipple are found corpuscles of similar structure, called *genital corpuscles*.

END BULBS OF KRAUSE. Similar to the preceding corpuscles, except that the nerve ending is more expanded and the capsule is less pronounced in structure, the end bulbs of Krause are widely distributed in the subcutaneous connective tissue, averaging about 15 to a square centimeter. They are the end organs for sensations of cold.

END ORGANS OF RUFFINI. These structures are more complex in structure than the end bulbs of Krause, although they resemble them. They are believed to mediate the sensation of heat, and possibly movement, in connective tissue. They are less numerous and more deeply situated in the tissue than are the end bulbs of Krause.

CORPUSCLES OF MEISSNER. These are elongated elliptical bodies, in which endings of both myelinated and unmyelinated fibers are found. The nerve fibers end in flattened processes within and between the cells of the corpuscles. They are numerous in the skin, especially on the tips of the fingers and toes and on the palms of the hands and the soles of the feet. Corpuscles of Meissner are usually found in the dermal papillae lying in close contact with the epidermis.

Mechanism of Cutaneous Sensations. The receptors and afferent pathways associated with the cutaneous sensations, along with certain significant phenomena, are discussed in the paragraphs which follow.

TOUCH: Receptors. Receptors for touch include the corpuscles of Meissner, Merkel's tactile discs, hair-root plexuses, and nonencapsulated glomeruli. **Afferent Pathway.** Impulses pass through large myelinated fibers of cranial and spinal nerves. Axons of spinal sensory neurons enter the cord and pass upward and downward in the posterior funiculus. Some fibers synapse with cells in the gray matter. Axons of these secondary neurons cross to the other side of the cord and continue upward in the ventral spinothalamic tract to the brain. In the brain their course is not certain, but it is believed that synapses with tertiary neurons occur and that impulses reach the cerebral cortex by way of the thalamus. The touch center is in the general sensory area.

PRESSURE: Receptors. Receptors for pressure include the corpuscles of Vater-Pacini and the genital corpuscles. **Afferent Pathway.** Same as for touch impulses.

TEMPERATURE: Receptors. The receptors for cold are the end bulbs of Krause; for heat, the end organs of Ruffini. **Afferent Pathway.** Impulses for the sensation of temperature pass through small, poorly myelinated fibers in cranial and spinal nerves. Those entering the spinal cord synapse with secondary neurons whose axons pass upward in the *lateral spinothalamic tract* along with those carrying pain impulses. On reaching the thalamus, such impulses may give rise to crude, uncritical temperature sensations. These impulses are relayed by the thalamus to the sensory or somesthetic area of the cortex.

PHENOMENA ASSOCIATED WITH TEMPERATURE SENSATIONS. Any change in temperature of the environment is a normal stimulus to the heat and cold receptors, the sensation being relative and dependent on the *degree of the change and the preceding conditions*. To illustrate: If the two hands are placed in water, one in hot and the other in cold, for a short while, and if both are transferred to warm water,

then to the hand that has been in cold water the warm water will feel hot, but to the hand that has been in hot water the warm water will feel cold.

Temperature sensations are *poorly localized*; that is, they are felt over a considerable area around the spot that is stimulated. But *adaptation* occurs readily; for example, upon immersion of the body in water below body temperature, the water feels very cold, but, after remaining in it for a short time, one becomes accustomed to it. Bath water may feel almost unbearably hot at first, but again the body quickly adapts to it.

There is considerable variability in the *sensitivity of various parts of the body* to temperature changes. On exposed surfaces (face, hands, legs), the temperature sense is poorly developed. On the chest, abdomen, and anterior surface of the arm, it is highly developed. Internal organs are relatively less sensitive to extremes of temperature. Hot foods or liquids may cause pain in the mouth, and even in the esophagus, but by the time they have reached the stomach the sensation is all but lost. Hot enemas are not felt above the rectum.

SENSATIONS OF PAIN

Pain is a primitive sensation and of great importance to the state of health and even the life of an individual. As a reflection of disorder within the body, for example, it provides a warning. But whatever the stimulus for pain may be, the important fact is that the reaction of the individual, whether limited in scope or generalized, serves either to protect the body or to withdraw it from the source of the stimulus.

Receptors. Sensations of pain are mediated by naked or free nerve endings.

Afferent Pathways. The path of nerve impulses for pain is through small, poorly myelinated fibers of cranial and spinal nerves. Those entering the spinal cord pass upward and downward only a few segments in Lissauer's tract, then pass into the posterior horn of the gray matter, where they synapse with secondary neurons whose axons pass across the cord and ascend in the *lateral spinothalamic tract*. These axons terminate in the thalamus, where they synapse with neurons of the third order, which terminate in the sensory or somesthetic areas in the cortex.

Phenomena Associated with Pain Sensations. Several phenomena associated with sensations of pain are worth noting:

1. Pain receptors may be stimulated by any type of stimulus. Overstimulation of receptors for other sensations (touch, pressure, heat, cold) may initiate pain impulses. In visceral organs, excessive distention or dilation of an organ, excessive muscular contraction or spasm,

inadequate blood supply, or the presence of chemical substances may give rise to pain impulses.

2. There are two types of pain impulses: (a) Those which first occur following painful stimulation. They are strong and travel rapidly in the poorly myelinated fibers, but disappear quickly after cessation of the stimulus. (b) Those which are weak and travel slowly in nonmyelinated fibers. They persist for a considerable time after the stimulus is withdrawn.

3. Adaptation to pain does not readily occur.

4. In most cases, painful stimuli are harmful to the body.

5. Pain is an indicator of disease or disorder in the body. It is one of the cardinal symptoms of inflammation.

Referred Pain. Pain arising from stimulation of pain receptors on the surface of the body can usually be fairly well localized; that is, the cerebral cortex projects the pain sensation to the point of stimulus or its vicinity. When, however, pain arises from stimulation of receptors in the visceral organs, the sensation is not projected back to the point of stimulation; instead, the pain may be felt in the skin or in some surface area, often quite remote from the point of stimulation. This is known as *referred pain*. Such pain may result in a feeling of tenderness in the skin and a tensing of skeletal muscles. In general, the area to which the pain is referred is one which receives its innervation from the same segment of the cord through which the visceral organ receives its nerve supply.

An understanding of the mechanism of referred pain is of distinct advantage to the physician in the diagnosis of internal disorders. The accompanying brief table shows some of the general cutaneous areas to which visceral pain is referred.

| <i>Pain in</i> | <i>May be Referred to:</i> |
|-------------------------|--|
| Heart (angina pectoris) | Chest and medial surface of left arm |
| Liver | Region over the right scapula |
| Stomach | Region over ensiform cartilage or upper portion of the back |
| Kidney | A large area over the lower portion of the abdomen and back and over the lateral and medial portions of the thigh. |
| Ovaries | Region inferior and lateral to umbilicus |

Referred pain may also occur in peripheral nerves. When a nerve is stimulated somewhere along its course, the sensation is usually referred back to the region supplied by the afferent fibers customarily receiving the stimulus. In this way, pressure on the sciatic nerve in the thigh may cause a tingling feeling in the foot; similarly, irritation of the severed end of a nerve in an amputated appendage may cause sensations to be referred to the part that has been cut off (known as a

"phantom limb"). Pain may also be referred to a part supplied by a branch of the nerve stimulated, as in the case of an infected tooth in the lower jaw, which may cause pain to be referred to the region of the maxillary sinus, the orbital region, or the ear (all of which parts are supplied by branches of the trigeminal nerve).

Headache. It is curious to note that, although the pain center is in the brain, the brain tissue itself is relatively insensitive to pain either from cutting or from manipulation. Yet headaches, or diffuse pain in the head region, are quite common. In the majority of instances, the cause of a headache is some physiological condition or other factor that is operating outside the cranial activity. Headaches may be confined to specific lobes or they may be quite general. They may be unilateral or bilateral. They may be continuous, intermittent, or throbbing. The range of their intensity is great: from dull pain to acute and almost unbearable pain.

Some common causes of headaches are: (1) disturbances of the alimentary tract, such as constipation; (2) toxemias, such as those associated with nephritis, jaundice, or sinus infection; (3) eye disorders, eyestrain; (4) changes in intracranial pressure, as in meningitis; (5) concussion or compression of the brain, as in skull fracture or in brain tumor; (6) excessive (or abnormally reduced) intracranial blood pressure; (7) emotional states, such as worry, anxiety, and anger; and (8) the onset of febrile diseases, such as typhoid fever, pneumonia, scarlet fever, smallpox, and (9) inflammation of the meninges.

Psychogenic Pain. It is not uncommon for pain to occur which appears to be symptomatic of disorder in a particular organ, for which no organic pathology can be found to account for the pain. If an emotional mechanism can be demonstrated, such pain is said to be *psychogenic*. If a neurological mechanism can be demonstrated, it is called *neurogenic*.

Pains of this nature are very real, and not imaginary, as is commonly supposed. They frequently lead to surgery for the removal of sound organs, through wrong diagnosis. Not infrequently it happens in such cases that after the suspected organ has been removed the pain manifests itself in another organ, and the unnecessary resort to surgery may be repeated.

It is now believed that psychogenic pain and the organ malfunctioning that may accompany it can be the results of the body's reaction to certain emotions, such as fear, hate, worry, or resentment, or to conflicts and frustrations related to the personality. Many of these conditions have their origin in the early life of the individual, long before the onset of the organic disturbance. The treatment of such conditions requires the special experience and knowledge of a psychiatrist.

PROPRIOCEPTIVE SENSATION (KINESTHETIC SENSE)

The proprioceptive sensations provide the individual with awareness of the activities of muscles, tendons, and joints, and, more generally, with an appreciation of position and movement (the kinesthetic sense).

Receptors. Proprioceptive receptors are located in muscles or tendons or in the connective tissue surrounding muscle fibers. They include: epilemma endings, interstitial endings, and neurotendinous spindles.

EPILEMMA ENDINGS. These are the fine terminations of sensory fibers on the sarcolemma of muscle fibers. They are of two types: simple spindles and neuromuscular spindles.

Simple Spindles. The axon branches and envelopes the fiber by many tortuous twists and convolutions. The fibers end in small nodules.

Neuromuscular Spindles. These are long, narrow complex epilemma endings consisting of one or several striated muscle fibers enveloped in a connective tissue capsule. The fibers within the spindle (*intrafusal fibers*) are smaller than typical muscle fibers, and each also bears a motor end plate, the end of a motor fiber. Within the capsule the sensory nerve fibers come into close contact with the fibers by means of either of two kinds of endings, namely, *spiral* and *branched* (*flower-spray*); the latter are nearest to the termination of the fiber.

INTERSTITIAL ENDINGS. These are simple naked nerve endings, though some may be encapsulated structures. They lie in connective tissue between muscle fibers or in the fascia surrounding the muscle.

NEUROTENDINOUS SPINDLES (GOLGI TENDON ORGANS). These are similar in structure to the neuromuscular spindles, except that the sensory fibers are entwined about the collagenous fibers of the tendon instead of about muscle fibers.

Other proprioceptors are Pacinian corpuscles, which are found in tendons, ligaments, and fascia; and end organs of Ruffini, which are found in tendons and naked nerve endings between muscle and tendon fibers.

Mechanism of Muscle Sensations. It is believed (*a*) that the stretch of a muscle stimulates the spiral endings about the intrafusal fibers of a neuromuscular spindle, and as a result impulses are dispatched which result in the sensation of muscular tension; (*b*) that submaximal contraction is registered by the neurotendinous spindles; and (*c*) that maximal contraction is registered through stimulation of the branched endings of the neuromuscular spindle. Further, it is thought that the interstitial endings are stimulated by the change in shape of the muscle fibers, and that the free nerve endings probably react to chemical changes taking place during muscular contractions.

The hydrogen ions of lactic acid probably act as a stimulus in the *sensation of fatigue*.

Afferent Pathway. Proprioceptive impulses are conducted by fairly large, myelinated fibers in the cranial and spinal nerves. The fibers in the spinal nerves enter the cord through the posterior roots. Within the cord the axons may take one of two courses: (1) Through the *fasciculus cuneatus* and *fasciculus gracilis* of the dorsal funiculus to the corresponding nuclei of the medulla, where they synapse with secondary neurons, whose axons cross over and terminate in the thalamus with tertiary neurons; these neurons relay the impulse to the somesthetic centers of the cortex. (2) Through the *dorsal spinocerebellar tracts*, which are composed of axons of second-order neurons whose cell bodies lie in the gray matter of the cord; their axons ascend in the lateral funiculus and terminate in the cerebellum; from here impulses are relayed to the red nucleus of the midbrain. Such impulses are involved in "unconscious muscle sense" and also in muscular coordination.

The Role of Proprioceptive Sensations. Through the proprioceptive or kinesthetic sense, one is able to judge the position of various parts of the body at a given time; to realize the extent of muscular contractions; to estimate weight; and to determine the muscular effort necessary to perform work. The proper functioning of this sense is essential in the control and coordination of muscular movements and in the maintenance of muscle tone that is vital to normal posture.

Proprioceptive sensations are the key to satisfactory performance of complex or skilled activities or movements. Such activities as dressing in the dark, playing the piano, touch typing, and all athletic activities depend primarily on the ability to bring various parts of the body into definite positions at specific times. Such can be accomplished only when exact information is provided by the muscle and joint receptors. The precise degree to which these sensations can be developed is illustrated by the ability of blind persons to judge distance or to recognize objects by their shape, size, or position through this proprioceptive sense. It must be admitted, however, that we are only vaguely conscious of the muscle sense. When asked to describe how we know that our arm or leg is in a given position, we say we "feel" it, but the "feeling" is vastly different from that involving the sense of touch.

Disorders of the Proprioceptive Sense. In the condition known as *tabes dorsalis*, the fibers in the posterior funiculi of the spinal cord are destroyed, thus preventing proprioceptive impulses from reaching the brain. From this condition develops *locomotor ataxia*, in which there is marked disturbance in walking; the patient is unable to judge the position of his legs without looking at them and is unable to stand erect with his eyes closed (*Romberg's sign*).

THIRST, HUNGER, APPETITE, FATIGUE

There are some sensations registered by the cerebral cortex, principally internal in origin, for which no specific end organs or receptors have been identified. Among them are thirst, hunger, appetite, and fatigue.

Thirst. This sensation is associated with reduced water content of the body. The origin of thirst may be local (inhalation of excessively dry or dusty air) or general (following hemorrhage, profuse sweating, or loss of water through diarrhea, vomiting, or excessive renal functioning, as is seen in diabetes). Reduced salivary secretion (as from dryness of the mouth, tongue, or pharynx) is another stimulus for the sensation of thirst.

There is evidence that osmoreceptors located in the supraoptic nucleus of the hypothalamus are sensitive to changes in the osmolarity of the blood. Reduction in water content stimulates these cells, increasing secretion of the *antidiuretic hormone* (ADH) by cells of the hypothalamus; it is released from posterior lobe of hypophysis. Water loss through the kidney is thus reduced.

Hunger. The sensation of hunger, projected to the region of the stomach, is due to impulses initiated by the rhythmic contractions of the muscles in the wall of that organ. These contractions last about thirty seconds and may occur for periods of thirty to forty-five minutes. Following such a period there is usually one of rest, lasting from one-half to two and one-half hours before the hunger pangs resume.

Hunger contractions are not due to need for food; they may occur while food is still in the intestine. Indeed, after two or three days of starvation they disappear. Filling the stomach with food (or even indigestible bulk substances) will, however, *inhibit* the contractions. A reduction in the amount of blood sugar will *increase* hunger contractions (as seen after the injection of insulin). Vigorous exercise, smoking, or swallowing of water tend to inhibit them, and emotional states (fear, anger, elation) may cause them to cease entirely.

Appetite. This sensation is similar to that of hunger but differs from it primarily in that, while hunger sensations are unpleasant and localized, appetite sensation is pleasant and generalized. Appetite is the desire for food and the ability to eat and enjoy it. To some degree, it is instinctive, yet both experimental animals and human beings tend to lose the desire for food and will refuse to eat it if they are fed for a protracted time on a monotonous and inadequate diet. It is curious to note that both will, if given a choice of foods, tend to select those which supply dietary deficiencies; man is somewhat less efficient in this respect than are the experimental animals and therefore needs to plan his diet in order to avoid deficiencies.

Appetite is largely *determined* by conditioned reflexes. Odors, the sight of food, or even the thought of food may excite this sensation. Certain specific substances in foods (called *secretagogues*) stimulate the appetite (and explain the use of so-called "appetizers" at the beginning of meals). Not the least of the factors involved in appetite are the appearance of foods and the conditions of the external environment in which they are being eaten. Metabolic conditions, too, affect the appetite. Muscular activity increases it; a good appetite is associated with general muscle tonus as well as the tonus of the stomach muscles.

Two centers in the hypothalamus exert a neural control over food intake. These are (1) a *hunger or feeding center* and (2) a *satiety center*. Lesions of these centers may result in abnormal feeding habits.

Disorders of the appetite result from a number of factors. In diseased states it may be greatly reduced, as it also is when specific substances (for example, thiamine) have been omitted from the diet. Emotional disturbances have a profound effect on appetite; disgust, fear, and anger tend to reduce it, while pleasant environmental conditions and general well-being favor it. Some prolonged emotional states may lead to excessive appetite, resulting in habitual overeating. Loss of appetite is called *anorexia*.

Fatigue. The sensation of fatigue may be fairly definitely localized (as when it is experienced in a finger, arm, or leg), or it may be generalized throughout the body. Specific end organs for fatigue have not yet been identified. Fatigue may be either acute or chronic. In *acute fatigue*, the onset is rapid and the sensation is relieved by rest. Such fatigue is usually of limited duration. Overactivity and the inroads of infectious diseases are common causes. In *chronic fatigue*, there is usually indication of some disturbance of metabolism. Among the possible causes of chronic fatigue are: (a) dietary deficiencies (inadequate intake of vitamins, mineral salts, proteins); (b) diseases (diabetes, anemia, tuberculosis, kidney infection, heart ailments, to name only a few); (c) endocrine imbalance, such as, for example, that which accompanies the menopause; (d) psychogenic factors (conflicts, frustrations, boredom, "neurasthenia"); (e) abnormal physical conditions, especially those which involve the skeleton and the muscles (poor posture, "fallen arches," and others).

OLFACTORY SENSE (SENSATIONS OF SMELL)

The olfactory is one of the basic primitive senses involving significant individual and social consequences.

Receptors. The olfactory sense organ consists of a specialized region of nasal epithelium lying in the upper portion of each nasal fossa and covering a part of the lateral wall, the roof, and the side of

the nasal septum. This epithelium is pseudostratified and contains three types of cells: *sustentacular* or *supporting* cells, *olfactory* cells, and *basal* cells.

SUSTENTACULAR (SUPPORTING) CELLS. These are tall cylindrical cells with narrow proximal portions. Their free surfaces are joined with those of adjoining cells to form a firm cuticle through which project the free ends of olfactory cells.

OLFACTORY CELLS. These are bipolar neurons which lie between the sustentacular cells. They are fusiform in shape and contain a centrally located nucleus. The distal or free end of each cell, which bears six or eight fine *olfactory hairs*, forms a tiny spiked knob that projects slightly above the cuticle. The proximal end forms a fine process (an axon) which passes through the basal portion of the epithelium, where it joins others to constitute groups of fibers (the *fila olfactoria*), of which there are about twenty. These continue through the cribriform plate to the olfactory bulb, where they terminate. The olfactory cells are the *receptors* for the sense of smell.

BASAL CELLS. These are small pyramidal cells lying between the bases of the supporting cells and the olfactory cells. They are thought to be replacement cells for the supporting elements.

Olfactory epithelium is kept moist by secretions of the *olfactory glands of Bowman*. Lying in the lamina propria, these glands are branched, tubuloalveolar structures whose narrow excretory ducts open on the olfactory surface.

Mechanics of Smell. The stimuli for the sense of smell are volatile gases whose molecules, on entering the nasal cavity, become dissolved in the mucous secretions, where they stimulate the olfactory cells. There is, however, some evidence that *radiant energy* given off by the molecules of the stimulating substance is the true stimulus rather than the molecules themselves. Impulses pass to the olfactory bulb, where they excite nonmyelinated fibers terminating in globular masses, the *olfactory glomeruli*. Here they synapse with *mitral cells*, whose axons form the core of the *olfactory tract*. This tract passes into the *lateral olfactory striae* and on to the hippocampal formation, a part of the rhinencephalon or olfactory cortex. Here the impulses are interpreted as an *odor*, giving rise to the sensation of smell.

The air in the olfactory region is still or quiet air, in contrast with the air currents which, in ordinary respiratory movements, pass through the relatively wide nasal passageways (meatuses) lying below the inferior, middle, and superior conchae. Gaseous substances can reach the endings of olfactory cells by diffusion from the nasal cavity or the pharynx. To perceive a faint odor more distinctly, however, we open wide the external nares by a forcible, quick inspiration (sniffing), which causes air to enter the olfactory region.

Classification of Odors. The classification of odors is difficult, chiefly because of the delicate nuances between them. Nevertheless, it is possible to recognize in a mixture of substances a number of different odors. One classification, which is based principally on the mechanism by which they are perceived, lists: (*a*) pure odors, the sensations for which arise from olfactory receptors in the nose only, (*b*) odors mixed with taste sensations, and (*c*) odors mixed with sensations arising from other receptors than those located in the nose. Pure odors have also been subdivided into nine groups: ethereal (fruits), fragrant (flowers), aromatic (benzene), ambrosial (perfumes, garlic, onions), burning (burnt wheat), goat (sweat), repulsive (garbage), and nauseating (excrement).

Special Phenomena Associated with Olfactory Sensations. When two substances are smelled simultaneously, the odor of one is recognized, then the other. Persistence, or memory of odors, is very pronounced. Once a substance has been smelled, its odor is usually recalled or recognized quite readily.

Adaptation to odors occurs rapidly. For this reason, one becomes accustomed to odors and is able to endure unpleasant ones. This also accounts for the failure of individuals to recognize a gas that is accumulating slowly in a room.

The sensation of smell is often confused with that of taste, since both may be aroused by the same chemical stimuli. Food flavors depend on odors; a raw onion eaten with the nose closed can scarcely be distinguished from a piece of apple or potato.

The sensation of smell is not so highly developed in man as in some of the lower animals, which depend on it to a greater degree in the securing of food and for detection of enemies.

The nasal epithelium, in addition to receiving the endings of olfactory nerves, is innervated by sensory fibers from the trigeminal nerve, which supplies the nonolfactory nasal epithelium. These latter fibers mediate sensations of pain, cold, heat, tickling, and pressure.

The sense of smell plays an important role in *sexual selection* and *mating activities*. It is useful to a physician in the diagnosis of disease; some diseases have a characteristic odor.

The *threshold stimulus* for stimulating olfactory cells is extremely low for some substances. For example, one of the mercaptans can be detected in concentrations as low as 1 :60,000,000,000 gm. in a liter of air. Other substances, such as carbon monoxide, fail to arouse any sensation.

GUSTATORY SENSE (SENSATIONS OF TASTE)

The olfactory and gustatory senses previously were referred to collectively as the "chemical senses." More recent studies, however, have

indicated that the stimulus for smell is probably more physical than chemical in nature. There is evidence, too, that taste differences of individuals have a hereditary basis.

Receptors. Taste is perceived through the mediation of the *gustatory cells* in taste buds. *Taste buds* are ovoid bodies found in the epithelium of the buccal cavity and the pharynx. Each is a barrel-shaped structure averaging about 70 microns in length. The distal end of each taste bud opens through the surface layer of epithelial cells. This opening is called the *gustatory* or *taste pore*. Within each taste bud are two types of cells: the *gustatory* and the *supporting*. The latter are spindle-shaped and enclose from four to twenty gustatory cells, each of which bears at its distal end a *taste hair*, which projects through the gustatory pore. At the basal end of the taste bud is an opening through which nerve fibers enter. The fibers ramify among the taste cells and end as small knots between the cells.

Taste buds are, of course, most numerous on the tongue, but they are also found on the soft palate, the anterior pillar of the fauces, the posterior wall of the pharynx, the upper and lower surfaces of epiglottis, and the posterior wall of the larynx. On the tongue they are found mostly on the fungiform and vallate papillae. A single vallate papilla may bear from two to three hundred taste buds, whose pores open into the circular furrow that surrounds the papilla.

Afferent Pathway. The nerves which supply afferent fibers to taste buds are: (a) the lingual branch of the chorda tympana of the facial (VII) nerve, which supplies the anterior two-thirds of the tongue; (b) the glossopharyngeal (IX) nerve, which supplies the posterior third of the tongue; and (c) fibers of the vagus (X) nerve, which supply the epiglottis and the lower pharynx. Fibers from these three nerves enter the medulla oblongata and terminate in a gustatory nucleus lying just below the fourth ventricle. From this nucleus, connections are made with the thalamus and the cerebral cortex; it is in the cortex that the impulses produce taste sensations. These pathways have not been fully worked out, but there is evidence that the mammillary bodies correlate gustatory and olfactory responses. It is further suspected that there are receptors other than those in taste buds which mediate taste sensations, for it is known that gustatory sensation may arise in areas where there are no taste buds.

The Nature of Taste. To be tasted, substances must be in solution. If the surface of the tongue is dry, no taste is experienced when sugar is placed on it. Insoluble substances have no taste. The exact nature of the stimulus giving rise to a taste sensation and the nature of the process of exciting the gustatory cells are at present not known.

Classification of Gustatory Sensations. Sensations of taste that are easily recognized fall into four primary groups, namely, *sour*, *salty*, *bit-*

ter, and *sweet*. There is no specific correlation between the taste of various substances and their chemical composition. Crystalloid substances are usually effective in arousing gustatory sensations; colloids are relatively inactive in this respect.

Sour tastes are characteristic of acids, the sourness being attributed to the presence of hydrogen ions. *Salty tastes* are characteristic of chlorides, nitrates, sulfates, and other similar compounds. *Bitter tastes* are induced by substances such as alkaloids (quinine, morphine), some glucosides, bile salts, and many plant extractives. Most of these substances have a toxic or depressant effect on cellular activities. *Sweet tastes* are characteristic of organic substances, such as sugars, alcohols, and their derivatives.

Special Phenomena Associated with Gustatory Sensations. The tongue is not equally sensitive to taste sensations at all points. Sweet tastes are registered mainly at the tip of the tongue, bitter at the back or root, salt at the tip and sides, and sour at the sides. This would indicate that there are different receptors for each type of taste, but anatomical differences among taste buds have not been discovered.

Taste sensations of particular substances are not always predictable. For most individuals, benzoate of soda has no taste; others may find it bitter or sweet. Lemonade tastes sour after something sweet has been taken into the mouth, a sign that *contrast* plays a role. Certain tastes are *complementary*; that is, they tend to neutralize one another; a sweet syrup takes the sourness out of lemon juice and lemon juice takes the sweetness out of syrup.

CHEMICAL SENSE

Chemical substances have been considered the principal stimuli of olfactory and gustatory cells. It is believed that there may also be a *general chemical sense*, with receptors widely distributed in the skin and the mucous membranes. The sensation is almost exclusively one of irritation. Many substances give rise to such irritation, including, for example, ammonia, sulfur dioxide, and similar "foreign agents." Because the sensation is aroused in areas where no special end organs are present (for example, the cornea of the eye), it is suspected that the receptors are the free nerve endings.

VISUAL SENSATIONS

Three structural units are operative in the functioning of the visual organ: the *eyeball* (fibrous tunic, vascular tunic, nervous tunic, and refractory media), wherein lie the sensory receptors of vision; the *accessory structures* (eyebrow, eyelid, conjunctiva, lacrimal apparatus, ocular muscles); and the *orbit* that encloses the eyeball.

To obtain a preliminary understanding of visual function, one has

only to sketch a comparison of the structure of the eye with that of a camera, for, in the last analysis, each is an apparatus so constructed as to produce an image on a light-sensitive surface. Similarities are shown in the following table.

COMPARISON OF THE EYE WITH A CAMERA

| <i>Phenomenon</i> | <i>In a Camera</i> | <i>In the Eye</i> |
|---|--|--|
| Pigment-containing wall | Box | Sclera and choroid |
| Light-sensitive surface | Film or plate | Retina |
| Light-regulating mechanism | Diaphragm | Iris |
| Mechanism for admitting or shutting out light | Shutter | Eyelid |
| Refracting media | Lenses and air | Cornea, aqueous humor, lens, vitreous body |
| Focusing mechanism | Adjustment of distance between lens and film | Alteration of shape of lens |
| Development of image | In darkroom, on film | In cortex of brain, in consciousness |

The Eyeball (Bulb of the Eye)

The eyeball comprises three coats, or *tunics*, which contain the refracting media.

Coats of the Eyeball. The three tunics of the eyeball are: the *fibrous tunic*, composed of the *sclera*, and *cornea*; the *vascular tunic*, or *uvea*, composed of the *choroid*, the *ciliary body*, and the *iris*; and the *nervous tunic*, or *retina*.

FIBROUS TUNIC. The fibrous tunic of the eyeball consists of the *sclera* and the *cornea*.

Sclera. The sclera is a firm, dense membrane, white in color, forming the *outermost layer* of the eye. It is semirigid, maintaining the shape of the eyeball and protecting its inner parts. To the sclera are attached the eye muscles and the surrounding fascia. Posteriorly, it is thicker than elsewhere. It is pierced by the optic nerve.

Cornea. The *most anterior* portion of the fibrous tunic, the cornea forms about one-sixth of the surface of the eyeball. It is transparent and projects anteriorly, forming a curved convex structure. At its periphery, the outer layer of the cornea is continuous with the conjunctiva lining the space between eyelid and eyeball. The layers of the cornea are: (1) the *outer epithelium*, stratified squamous in type, (2) *Bowman's membrane*, (3) the *substantia propria* (which constitutes about 90 per cent of the cornea), (4) the *membrane of Descemet*, and (5) the *corneal endothelium*. Blood vessels are not found in the cornea, but it is well supplied with nerves and lymph vessels. Near the junction of the cornea and the sclera, a venous sinus, the *canal of*

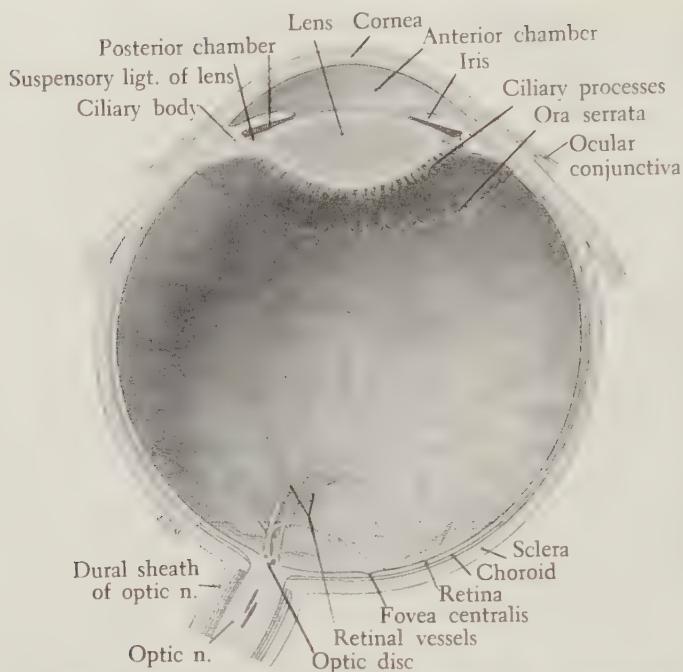


Fig. 5-2. Horizontal section through eyeball. (Reprinted with permission of St. Martin's Press and The Macmillan Company, Ltd. from Hamilton, *Text-book of Human Anatomy*, 1956.)

Schlemm, passes circularly around the former; from this arise the *anterior ciliary veins*.

VASCULAR TUNIC. The vascular tunic of the eyeball consists of the choroid, the ciliary body, and the iris.

Choroid. The choroid is the *middle* layer of the eyeball, investing about five-sixths of its posterior portion. It is a thin, dark brown, highly vascular membrane lying within the sclera, to which it is firmly united. It contains many small arterioles and venules which terminate in a dense capillary plexus. Anteriorly, the choroid is continuous with the ciliary body and the iris.

Ciliary Body. The ciliary body lies at the junction of the choroid and the iris. It consists of three parts: the ciliary ring (*orbiculus circularis*), ciliary processes, and the ciliary muscle. Anterior to the *ora serrata* (the anterior border of the sensory portion of the retina) lies a circular band 3 to 4 mm. wide that bears shallow, radially directed grooves; this is the *ciliary ring*. Continuing anteriorly is a circular row of medially directed ridges, about 70 in number, constituting the *ciliary processes*. The inner surface of these ridges serves as a point of attach-

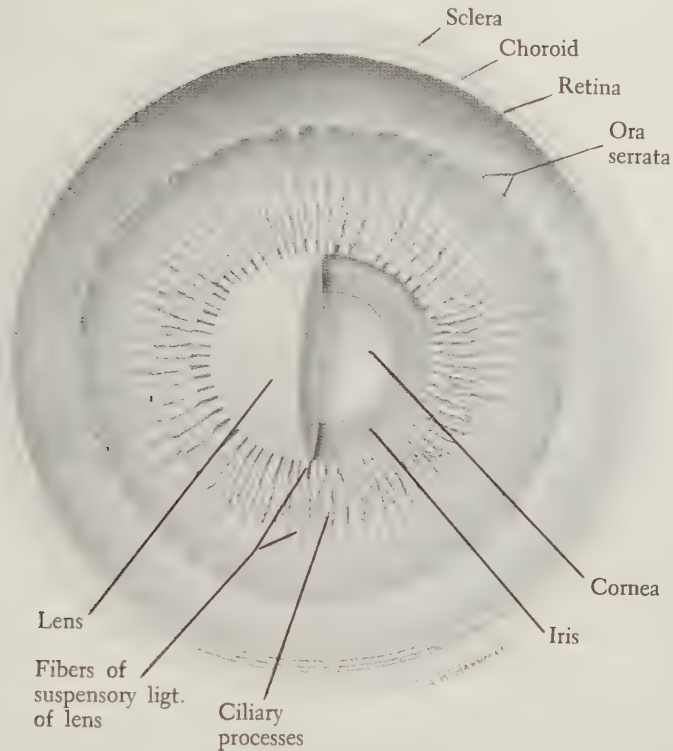


Fig. 5-3. Anterior half of eyeball seen from behind to show the relationships of the ciliary body. The vitreous body and half of the lens have been removed. (Reprinted with permission of St. Martin's Press and The Macmillan Company, Ltd. from Hamilton, *Textbook of Human Anatomy*, 1956.)

ment for the suspensory ligament, which supports the lens. Lateral to these processes is a mass of smooth-muscle fibers, the *ciliary muscle*, which is composed principally of *meridional fibers* and *circular fibers*. The ciliary muscle is the principal agent for changing the shape of the lens in accommodation. (Accommodation is explained on page 162.)

Iris. The anteriormost portion of the vascular coat is the iris, a thin, colored circular disc suspended between the cornea and the lens, which divides the space into an *anterior chamber* and a *posterior chamber*. Its lateral margin is continuous with the ciliary body; its medial margin forms the edge of a circular central opening, the *pupil*. The iris contains two types of smooth-muscle fibers: (a) *circular fibers*, which form a sphincter surrounding the pupil and serve to *constrict* (or narrow) the pupil, and (b) *radiating fibers*, modified myoepithelial

cells extending from the pupil to the periphery, which serve to *dilate* (enlarge) the pupil. The circular fibers are supplied by parasympathetic fibers of the autonomic nervous system, the radial fibers by sympathetic fibers.

The *color of the iris* is due to the presence of pigment cells containing dark-brown granules of melanin. In "blue" eyes, the pigment is principally in posterior layers of the iris; in "gray" and dark-colored eyes, the pigment is distributed generally through all layers. In albinos, this pigment is absent.

The *function of the iris* is to regulate the amount of light that can enter the eye. This is accomplished reflexly through contraction of the sphincter and dilator muscles. When a *bright* light enters the eye, or the eye accommodates for near vision, the circular fibers (sphincter muscle) contract and the pupil is reduced in size. When the light is *dim*, or the eye accommodates for far vision, the radial fibers (*dilator muscle*) contract and the size of the pupil increases, permitting more light to enter.

NERVOUS TUNIC OR RETINA. The retina is a delicate membrane forming the third and innermost layer of the eyeball. It consists of three portions: (1) the *pars optica retinae*, extending from the optic nerve, with which it is continuous anteriorly to a wavy line, the *ora serrata*, which lies a short distance behind the ciliary body; the *pars optica retinae* is the light-sensitive portion on which images are formed; (2) the *pars ciliaris retinae*, continuing forward from the *ora serrata* and forming the internal covering of the ciliary processes, and continuous with (3) the *pars iridica retinae*, which continues to the margin of the pupil and forms the posterior pigmented layer of the iris. The last two portions of the retina are nonsensitive to light rays.

Layers of the Retina. The retina consists of an *outer*, pigmented layer and an *inner*, nervous layer (the retina proper). The retina proper is made up of three sets of neurons whose cell bodies and processes are arranged to form ten layers; two of these are layers of supporting tissues (the internal and external limiting membranes). From within outward, these layers are: (1) *internal limiting membrane*; (2) *stratum opticum*, a layer of nerve fibers which are a continuation of the fibers of the optic nerve; (3) *ganglionic layer*, containing the cell bodies of neurons whose axons form the fibers of the stratum opticum; (4) *inner plexiform layer*, a dense reticulum of nerve fibers consisting of dendrites of the ganglionic layer and axons of the next (inner nuclear) layer; (5) *inner nuclear layer*, containing the cell bodies of three types of cells, the most numerous of which are bipolar cells; (6) *outer plexiform layer*, a dense network of axons and dendrites of cell bodies lying in the inner nuclear layer; (7) *outer nuclear layer*, containing the nuclei of the rods and cones of the next layer; (8) *external limiting*

membrane; (9) *rods and cones*, the visual receptors; (10) the *pigment epithelium*, consisting of cells containing a melanin called *fuscine*.

Rods and Cones. Rods and cones of the retina are modified dendrites of specialized neurons which function as the end organs or light receptors. Light rays must pass through all the several layers of the retina in order to reach the rods and cones.

The *rods* are the more numerous, there being an estimated one hundred million. They contain a pigment called *rhodopsin* or *visual purple*, which is bleached by light. It is believed that the decomposition of this substance from the action of light causes excitation of the rods. The rods are concerned primarily with vision in dim light.

The *cones* are the less numerous, there being an estimated seven million. They are concentrated in the posterior portion of the retina. The cones are involved in fine discrimination and color vision. Their precise exciting mechanism has not yet been determined.

Macula Lutea. In about the exact center of the posterior portion of the retina there is an area known as the *macula lutea*, or "yellow spot." In the center of this spot is a tiny depressed area, the *fovea central's*. In this area all layers of the retina are absent except the sensitive layer, in which *only cones* are present. Here is the area of keenest vision, the point upon which light rays are focused when the eye is directed toward an object. The foveal cones are long and closely set, and each connects with a single cell conveying the impulse to the brain.

Optic Disc or Blind Spot. A circular area lies to the nasal side of the fovea, marking the entrance of the optic nerve into the eye. At this point, nerve fibers received from all parts of the retina pass into the optic nerve. This area is the *optic disc*. Its circumference is slightly elevated, forming the *optic papilla*. No rods or cones are present; consequently, this point is insensitive to light, thus forming a "blind spot" on the retina. A *central artery* and *vein* enter and supply the retina as well as the optic nerve; the artery is a branch of the ophthalmic artery.

Refracting Media. Light rays, in order to reach the retina, must pass through four structures which constitute the *refracting media* of the eye. These are, in order, the *cornea*, *aqueous humor*, *crystalline lens*, and *vitreous body*.

CORNEA. The cornea forms the most anterior portion of the fibrous tunic. Its structure is described on page 149.

AQUEOUS HUMOR. The aqueous humor is a watery-like fluid filling the anterior and posterior chambers of the eye (the spaces between the cornea and the lens and suspensory ligaments). It is alkaline, containing some salts, principally sodium chloride. Aqueous humor is thought to originate by diffusion from capillaries of the ciliary processes. From the anterior chamber the fluid passes through the *spaces of Fontana*.

small spaces in the scleral meshwork at the *iris angle* (where the iris and the cornea join), and filters slowly into the *canal of Schlemm*. From this canal, a venous sinus, the aqueous humor passes to the larger veins of the eye.

CRYSTALLINE LENS. Immediately behind the pupil and anterior to the vitreous body lies a transparent biconvex body. It consists of a *lens substance* composed of lens fibers arranged in concentric lamellae. This substance is covered by a single-layered *lens epithelium*. The whole is enclosed in the elastic *lens capsule*. The crystalline lens is held in position by a series of fibers extending from the equator of the lens to the ciliary body. Collectively, these fibers form the *suspensory ligament* or *ciliary zonule*.

VITREOUS BODY. This body is a transparent, jelly-like mass which fills the cavity of the eye, lying between the lens and the pars optica retinae. Its anterior surface contains a concavity, the *hyaloid fossa*, in which lies the lens. The vitreous body adheres closely to the retina, especially at the ora serrata. Sometimes it contains a faint canal, the *hyaloid canal*, extending between the optic disc and the lens. This canal is a vestigial remnant of the hyaloid artery in the embryo.

Accessory Structures of The Eye

The accessory structures include: the eyebrow, the eyelids, the conjunctiva, the lacrimal apparatus, and the ocular muscles. Their functions are quite distinct and specialized.

Eyebrow. This thickened fold of skin, which covers the superior border of the orbit and bears many short hairs directed laterally, serves as a protective structure for the eye.

Eyelid. Two folds of the integument lie in front of the orbit of the eye. These, the eyelids, are movable structures which protect the eye from invasion by objects or from excessively bright light. They also serve to shut out light rays during sleep and to spread the lacrimal secretions over the anterior surface of the eyeball. The elliptical slit formed when the eyelids are open is the *palpebral fissure*. The angles at the lateral and medial junctions of the lids are the *palpebral commissures* or *canthi*. At the medial canthus there is a triangular space, the *lacrimal lake*, which is occupied by a reddish elevation, the *lacrimal caruncle*. The caruncle lies between two openings, the *puncta lacrimali*, each of which lies on the tip of a small elevation, the *lacrimal papilla*, located on the medial margin of each eyelid. It is through these openings that tears enter the lacrimal ducts.

Each eyelid is covered on its outer surface with skin which is continuous with the margin of the *conjunctiva*. Beneath the skin is a layer of loose subcutaneous connective tissue. Next is a layer of muscle, the *orbicularis oculi*. The fibers of this muscle form a sphincter which upon

contraction closes the eyelids. Attached to the upper portion of the upper lid is the *levator palpebrae superioris*, a muscle which raises this lid, thus opening the eye. In each lid posterior to the muscle fibers is a stiff plate of dense, fibrous connective tissue, the *tarsus*, which gives form to the lid. Within its substance are located the *tarsal* (*Meibomian*) glands, long, slender glands which open on the margins of the lids. Their secretion is sebaceous in nature and serves to lubricate the margins of the lids and to prevent the overflow of tears. At the margin of each lid are two or three rows of stiff, curved hairs, called *cilia* or *eyelashes*. Just posterior to these are the openings of enlarged and modified sweat glands called *ciliary glands*.

Conjunctiva. This is a mucous membrane lining the conjunctival sac, the space between the eyelids and the eyeball. The *palpebral portion* of the conjunctiva lines the lids and is reflected back and continuous with the *bulbar portion*, which covers a part of the sclera and the entire cornea. At the medial canthus it forms a semilunar fold, the *plica semilunaris*. At the margins of the lids, it is continuous with the skin. The *superior* and *inferior fornices* are arched folds which mark the junction of the palpebral and bulbar portions.

The conjunctiva lining the lids is of highly vascular composition. It may contain glands along the tarsal borders. In the region of the fornices, small lymph nodes are found. Over the sclera, the conjunctiva becomes thin, with few blood vessels; over the cornea, it is reduced to a single layer of epithelium.

Lacrimal Apparatus. The structures concerned with the secretion and release of tears constitute the lacrimal apparatus.

The *lacrimal glands* are two compound tubuloalveolar glands located at the upper lateral portions of the orbits. Each is about the size of an almond (average, 20 by 12 mm.) and consists of two parts: a *superior lacrimal gland* and an *inferior lacrimal gland*. From the inferior portion, excretory ducts, 6 to 12 in number, empty into the superior fornix of the conjunctival sac.

The *lacrimal secretion* (*tears*) passes medially and accumulates in the *lacrimal lake*, where it enters two small openings, the *puncta lacrimalia*, located on the *lacrimal papillae*. Through these it passes into two ducts, the *superior* and *inferior lacrimal ducts*, which converge medially and enter the *lacrimal sac* lying at the inner angle of the eye. From the lacrimal sac, with which it is continuous, a *nasolacrimal duct* conducts the secretion to the nasal cavity, where it opens into the inferior meatus. The secretion consists of a watery solution containing salts and some mucin. It is sterile and slightly antiseptic. On entering the conjunctival sac, tears are spread over the surface of the eyeball by the lids. They are normally carried away, through the lacrimal ducts or by evaporation, as rapidly as they are secreted. In the event that the

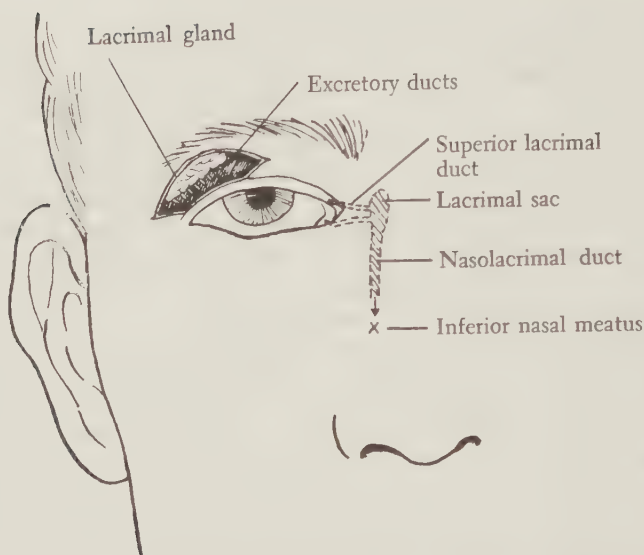


Fig. 5-4. Lacrimal apparatus. (Reprinted with permission of C. V. Mosby Company and the author from Francis, *Introduction to Human Anatomy*, 2nd ed., 1954.)

conjunctiva is stimulated by irritating substances (dust, bacteria, or injurious gases), or in certain emotional states, or as a result of pain, the lacrimal glands are activated and tears are secreted more rapidly than they can be carried away by the ducts. Under such conditions, the fluid accumulates and overflows the lids, this being the emotional reaction of "crying." Stoppage of the flow through the nasolacrimal duct, as occurs in inflammation of the nasal cavity, also results in accumulation of tears, or "watering" of the eyes.

Ocular Muscles. The ocular muscles are those which move the eyeballs and the eyelids. They include the *extrinsic muscles of the eyeball* (four recti and two oblique) and the *levator palpebrae superioris*, which raises the eyelid. Any specific movement of the eyeball usually necessitates action by two or more of the extrinsic muscles. The ocular muscles are striated and under voluntary control. All arise in the vicinity of the optic foramen.

EXTRINSIC MUSCLES. The extrinsic muscles controlling the movements of the eyeball include the recti and the oblique muscles.

Recti. The four recti muscles (superior, inferior, lateral, and medial) are inserted on corresponding surfaces of the eyeball. They originate at the apex of the orbit near the optic foramen. The recti act to turn the eyeball upward, downward, laterally, and medially, as their names

indicate. The rectus superioris is antagonistic to the inferior; the lateral is antagonistic to the medial.

Oblique. The superior oblique muscle arises at the apex of the orbit and passes anteriorly to the orbit's upper inner portion, where it becomes tendinous and passes through a fibrous loop, the *trochlea*, or "pulley." Here, bending at a sharp angle, it turns posteriorly and passes to the eyeball, where it is inserted on the upper surface between the superior and lateral recti. The *inferior oblique muscle* arises from the medial margin of the floor of the orbit. It passes laterally, upward, and backward and is inserted on the lower surface of the eyeball under the lateral rectus muscle. The oblique muscles act to rotate the eyeball on its axis.

Disorders of Extrinsic Muscles. Inequality in the action of opposing muscles may lead to a *squint*, or *strabismus*. If the eyes tend to converge, the condition is known as "cross-eye"; if they diverge, it is called "wall-eye." Both conditions cause double vision or *diplopia*.

LEVATOR PALPEBRAE SUPERIORIS. This muscle arises from the apex of the orbit and passes anteriorly to end in a wide aponeurosis, which is inserted in the upper portion of the eyelid and the fornix of the conjunctiva. It elevates the upper lid, opening the eye. Paralysis of this muscle results in *ptosis* (drooping of the lid).

The Orbit of the Eye

The cavities of the skull which enclose the eyeballs and their accessory structures are called the *orbits*.

Walls of the Orbit. The bones comprising the walls of the orbit are as follows:

| | |
|-------------------------|---------------------------------------|
| Superior wall | Frontal |
| Inferior wall | Maxilla, zygomatic |
| Lateral wall | Sphenoid, zygomatic |
| Medial wall | Maxilla, lacrimal, palatine, ethmoid. |

Note: The frontal, sphenoid, and ethmoid bones are single bones involved in the structure of *both* orbits.

Structure. The orbit is, in general, funnel- or cone-shaped, with its apex directed posteriorly, its broad end anteriorly. The rim of the orbit is formed by bony ridges of the frontal, zygomatic, and maxillary bones, which serve as protective structures. In the posterior wall the sphenoid bone bears two openings: (*a*) the *optic foramen*, a round opening that is located medially and transmits the optic nerve and ophthalmic artery; and (*b*) the *superior orbital fissure*, an irregular slit lying lateral to the optic foramen, which transmits the nerves innervating the ocular muscles (oculomotor, trochlear, abducens) and the ophthalmic branch of the facial nerve.

Fascia. This includes the structures lying within the orbit which bind together and support the eyeball and its related structures. The fascia includes: (1) the *periorbital* or *orbital periosteum*, which closely invests the bone forming the walls of the orbit. (2) The *orbital septum*, a fibrous sheet which extends partially across the anterior opening of the orbit, being continuous at its margin with the periosteum. (3) The *bulbar fascia* (*capsule of Tenon*), which forms a thin, fibrous, sheet enclosing all of the eyeball except the corneal portion. Its inner surface is smooth and forms a socket which permits limited movement of the eyeball. A continuation of the fascia encloses the optic nerve. The bulbar fascia separates the eyeball and the optic nerve from the orbital fat. (4) The *muscular fascia*, composed of thin fibrous sheets which enclose the ocular muscles; these are extensions of the sheaths of the medial and lateral rectus muscles attached to the walls of the orbits forming the medial and lateral check ligaments, which *restrain* eye movements.

Orbital Fat. In addition to the eyeball and its accessory structures, the orbit contains a considerable quantity of orbital fat. This fills the spaces posterior to the eyeball and serves as a protective cushion. In starvation and in certain forms of illness, this fat is absorbed, causing a shrunken appearance of the eyes (*endophthalmos*). On the other hand, tumors, abscesses, excess development of fat, or excessive activity of the thyroid gland may cause the eyeball to protrude (*exophthalmos*). Exophthalmos may also result from the contraction of certain smooth muscles lying outside the eyeball (Müller's muscle in the floor of the orbit, a muscle in the bulbar fascia, and the superior tarsal muscle of the upper eyelid).

Orbital Circulation. The orbit of the eye contains arteries and veins.

ARTERIES. The principal artery supplying the orbit is the *ophthalmic artery*. It is a branch of the internal carotid and enters the orbit through the optic foramen. The ophthalmic artery supplies the ocular muscles, lacrimal gland, and eyeball, and sends branches to the ethmoidal cells and nasal mucous membranes. A branch of this artery, the *central retinal artery*, passes through the optic nerve to the retina.

VEINS. The *superior* and *inferior ophthalmic veins* drain the orbits. They pass through the superior orbital fissure, sometimes as a single trunk, and empty into the cavernous sinuses.

LYMPHATIC VESSELS. These, as well as lymph nodes, are lacking in the orbital structures.

Orbital Nerves. The nerves innervating the orbital structures are:

1. "Mixed" nerves which carry *motor* impulses to muscles and *sensory* (proprioceptive) impulses to the brain. These include (a) the *oculomotor* (III) *nerve*, which supplies the medial, superior, and inferior recti and the inferior oblique muscle, the ciliary muscle, the

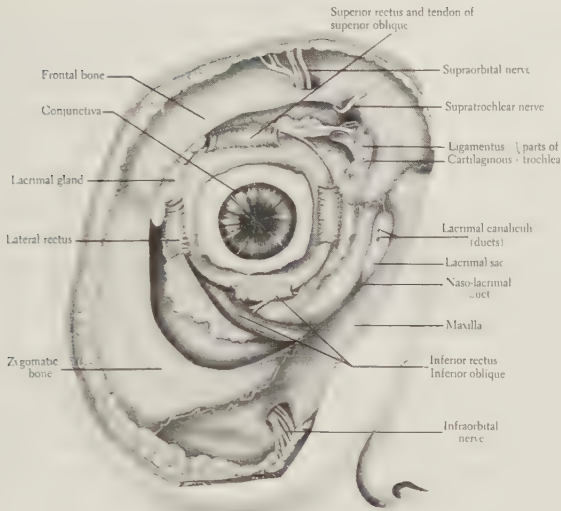


Fig. 5-5. Orbital cavity.

sphincter muscle of the iris, and the levator palpebrae superioris; (b) the *trochlear* (IV) nerve, which supplies the superior oblique muscle; and (c) the *abducens* (VI) nerve, which supplies the lateral rectus muscle.

2. The *ophthalmic branch of the trigeminal* (V) nerve. This supplies the cornea, the ciliary body, and the iris; the conjunctiva and the lacrimal gland; the mucous membrane of the nasal cavity and some of the sinuses; and the skin of the eyebrow, eyelids, nose, and forehead. It is strictly a *sensory* nerve.

3. *Autonomic nerves*. The ciliary muscle and sphincter fibers of the iris are innervated by fibers of the parasympathetic and sympathetic divisions of the autonomic nervous system. Postganglionic fibers of the *parasympathetic* division arise in the *ciliary ganglion*, which lies at the back part of the orbit; those in the *sympathetic* division arise from the *superior cervical ganglion*. The *lacrimal glands* are innervated by postganglionic fibers of the parasympathetic division from the sphenopalatine ganglion and by sympathetic fibers from the superior cervical ganglion.

Function of the Eye

The Mechanics of Vision. The eye is a mechanism in which the receptors (rods and cones) are stimulated by light energy, as a result

of which nerve impulses are initiated which pass to the visual area of the cerebral cortex, where they give rise to the sensation of sight. Visual sensations are of three types: *light*, *color*, and *form*. Although light is the principal stimulus for light sensations, an electric shock, or a blow, or even gentle pressure can cause a visual sensation. Such a sensation takes the form of a circle or flash of light ("seeing stars"), which may occur even in the dark or with the eyes closed. These sensations are called *phosphenes*.

LIGHT VISION. *Light* has two meanings. Subjectively, light refers to the sensation resulting from stimulation of the optic nerve endings; objectively, light or light energy consists of radiations which are capable of stimulating the optic nerve endings. Light rays vary in length. They travel at a speed of 186,000 miles per second. The rays that stimulate visual receptors and give rise to visual sensations range in wave length from 5000 to 7800 angstrom units; these are the radiations that produce the visible spectrum. Light rays of greater length (infrared rays) or lesser length (ultraviolet rays) constitute "black light"; that is, they do not give rise to visual sensations because receptors are not stimulated by them.

When light rays of the proper wave length enter the eye and strike the retina, they induce chemical changes in the rods and cones which initiate nerve impulses. These impulses are carried by the optic nerve to the cerebral cortex, where they give rise to the sensation of sight. The specific visual receptors are the rods and cones. Exactly *how* light rays stimulate them is not known. Numerous theories have been advanced, but none has been generally accepted. One that is rather widely held is the *duplicate theory of vision*, which maintains that the rods and the cones have distinct functions, the former functioning in dim light, the latter in bright light.

LIGHT AND DARK ADAPTATION. When one passes from a bright lighted room to a dark or dim room, it is impossible to distinguish objects for a time. Slowly the contents of the room begin to come into view and objects begin to take form. This process, by which the eyes have become adapted to vision in dimmer light, is called *dark adaptation*. The change is due to (a) regeneration of visual purple in the rods, which increases their sensitivity to light rays of lower intensity; and (b) dilatation of the pupil, which permits more light to enter the eye and strike the peripheral regions of the retina, where the rods predominate.

After the eyes have become dark-adapted, if the same person passes to a brightly lighted area, the new light has a dazzling effect and, for a short period, vision is poor. After a few seconds, however, the eyes become adapted. This process is called *light adaptation*. The change is the result of (a) bleaching of visual purple, reducing the sensitivity

of the rods; and (*b*) contraction of the pupil and partial closure of the eyelids, thereby reducing the amount of light entering the eye.

These two adaptive processes, according to the duplicate theory of vision, relates to the specialized functions of the rods and the cones. Dark adaptation makes *scotopia* or *twilight vision* possible. Light adaptation makes *photopia* or *daylight vision* possible.

Scotopia. Vision in dim light is the function of the *rods*, which have a low threshold of excitation; that is, they respond to light of low intensity. The rods are *not* concerned with *color* vision, their visual impulses being recorded in black or white or a combination of the two, namely, gray. The rods function in dim light and darkness, when color and detail are not discernible. In the rods is a reddish pigment, *rhodopsin* or *visual purple*, which, when exposed to light, becomes bleached. This condition is essential for stimulation of the rods. In the dark, the pigment is resynthesized. Rhodopsin is a protein linked to a pigment of the carotene group (vitamin A). Indeed, in the absence of vitamin A, rhodopsin cannot be formed and *night blindness* (inability to see in a dim light) results. Night blindness may also occur as a consequence of congenital lack of visual purple.

Photopia. Vision in bright light is the function of the *cones*, which have a high threshold of excitation; that is, light of high intensity is needed to elicit a response from them. They are operative in color vision and in the registering of the fine details of objects. When the eyes are directed toward an object, the retinal image falls upon the *fovea centralis*, a small, depressed area in the center of the macula lutea. At this point the retina is very thin and devoid of rods. This is the area of most acute vision. Surrounding the rod-free fovea, the retina contains both rods and cones, but the cones decrease progressively in number toward the periphery, where rods alone are present.

REFRACTION OF LIGHT. When light travels through a uniform medium, all the waves move at the same rate and in a straight line. However, should light rays pass from one medium to another (as from air to water), their velocity is altered and the rays are bent or *refracted*. When the light rays pass to a medium of *greater* density, they are bent *toward* a plane perpendicular to the surface of the two media. When they pass to one of *lesser* density, they are bent *away from* this perpendicular plane. The measurement of the ability of a substance to bend a ray of light is referred to as its *refractive index*. This index is a relative measurement; air is the basis for it, the refractive index of air being assumed to be 1.0. That of water is 1.33. Light rays, on entering the eye, must pass through the cornea, aqueous humor, lens, and vitreous body, to strike the retina. Accordingly, these are *refractive media*. All of them, with the exception of the lens, have the same refractive index as water; that of the lens is 1.44. The formation of an image

on the retina depends on the proper functioning of these refractive media.

INVERSION OF THE IMAGE. Owing to the refractive power of the lens, light rays passing through it cross each other and as a consequence appear on the retina in a reversed position. The result is an *inverted image*.

PROJECTION. When an image is formed on the retina, impulses are initiated which pass to the visual centers of the brain, where they are registered in consciousness as sight. Visual sensations, therefore, occur within the brain. But the brain immediately projects these sensations out of the body to the sighted objects, which reflect the light rays that have stimulated the retina. In the process of projection (a mental process), the retinal images are reinverted. This causes the object to appear as it actually is, that is, *right side up*.

ACCOMMODATION. To be seen clearly, an object must form a *sharply focused* image on the retina of each eye simultaneously. The process which enables one to see objects clearly at different distances is *accommodation*. It is dependent primarily on the elastic properties of the crystalline lens. When the eye is focused on a distant object, the surfaces of the lenses are *least convex* and their refractive power is at a minimum; this is *far vision*. When the eyes view an object nearer than about twenty feet, the lens surfaces become *more convex* and the refractive power of the lenses is at a maximum; this is *near vision*, in which the light rays enter the pupil and are brought into a sharp focus on the retina.

Mechanism of Accommodation. The crystalline lens is held in a state of tension by the pull of the suspensory ligament. Fibers of this ligament extend radially from the margin of the lens to the ciliary processes, to which they are attached. The ciliary processes are projections of the ciliary body, a part of the choroid coat of the eyeball. Intraocular pressure causes a pull to be exerted by the suspensory ligament, which reduces the curvature of the lens. This is the state of the lens when the eyes are at rest (that is, closed, or focused on objects twenty feet or more distant). In *far vision*, the light rays that enter the pupil of the eye are nearly parallel and are brought to a focus on the retina. In *near vision*, accommodation is necessary to bring about clear vision, which is accomplished by contraction of the *ciliary muscle*. The fibers of this muscle are so arranged that, when they contract, the ciliary body is pulled slightly forward, and this forward movement lessens the tension on the suspensory ligament, whereupon the lens, by virtue of its elasticity, becomes more spherical. This increases the convexity of the central portion of the anterior surface of the lens, increasing its refractive power and enabling light rays from objects to be brought to a focus on the retina.

Limits of Accommodation. There are limits within which the eye can accommodate. If an object is brought toward the eyes, at a certain point the image will begin to be indistinct or blurred. The shortest distance from the eyes at which an object can be seen clearly is called the *near point of vision*. For the average young adult, this averages about 10 inches; in infants it is much less (2 to 4 inches); in old people, it is much greater because the lens gradually loses its elasticity (and consequently its power to accommodate) with advancing age. After the age of 50 years, most individuals are unable to accommodate for near vision. This condition, called *presbyopia*, can be corrected by wearing glasses with convex curvature for close work. The farthest distance from the eyes at which an object can be seen clearly is called the *far point of vision*. This point is infinity, that is, any distance beyond 20 feet.

Near vision requires not only a change in the shape of the lens but also two other correlated adjustments. These are: (a) *convergence of the eyeballs*, by which the retinal images fall on identical or corresponding points to bring about single vision; and (b) *constriction of the pupil*, which permits light rays to pass through only the central portion of the crystalline lens, wherein lies the greatest refractive power.

Control of Accommodation. The ciliary muscle is composed of smooth muscle fibers innervated by fibers of the autonomic nervous system. Accordingly, accommodation is an involuntary reflex activity. The stimulus that initiates the reflex seems to be the contraction of the internal rectus muscles, which brings about the convergence that occurs in near vision. Voluntary control of the extrinsic muscles thereby automatically brings about coordinated activity of the ciliary muscles. The internal recti are innervated by the third cranial (oculomotor) nerve. Postganglionic fibers supplying the ciliary muscles arise in the ciliary ganglion, which lies just behind the eye.

Defects and Disorders of Accommodation. Disorders of the sensation of sight involving the mechanism of accommodation are: myopia, hyperopia, and astigmatism.

Myopia or nearsightedness arises when the anteroposterior diameter of the eyeball is longer than usual, a condition which causes the light rays to come to a focus slightly *in front of* the retina. Myopia can be corrected by the use of concave lenses, which will cause the light rays to diverge before they strike the crystalline lens of the eye. The myopic subject who has not had this condition corrected holds the object he wishes to see clearly close to his eyes; this indicates that his near point of vision is less than normal.

Hyperopia or farsightedness arises when the vertical diameter of the eyeball is greater than usual, a condition which causes the light rays to come to a focus slightly *behind* the retina. Hyperopia can be corrected with convex lenses, which cause the rays to converge before they strike the crystalline lens. In hyperopic subjects, the near point of vision is more than six inches

from the eyes. Consequently, to see any object, near or far, accommodation is necessary.

Astigmatism is due to irregularities in the curvature of the cornea or of the crystalline lens, most commonly the former. A very common defect, it is probably present to some degree in the eyes of all persons. The curved surfaces of the cornea and the lens normally represent segments of a sphere which cause the light rays to converge cone-like to a point of focus on the retina. However, if either surface is curved vertically more than horizontally, or vice versa, some parts of an object seen will be in focus and other parts will be out of focus. The result will be indistinct vision. Astigmatism is corrected with cylindrical lenses, which compensate for the irregular curvature. The commonest form of astigmatism is that in which the vertical curvature is greater than the horizontal curvature.

COLOR VISION. Colors have no objective existence; they exist only in our consciousness as subjective phenomena. What corresponds to "color sensations" in our environment are electromagnetic waves of various wave lengths. When light waves of various wave lengths strike the retina, they give rise to nervous impulses which, upon reaching the brain, are interpreted as colors.

White Light. "White light" is a combination of colored lights—red, orange, yellow, green, blue, and violet. These constitute the *spectrum* produced when white light is passed through a glass prism. The spectrum is essentially a scale of color wave lengths; each color, and each shade or gradation of a color, has a specific wave length. Furthermore, by mixing two or more colors, new color sensations are produced. White light, like many other colors, can be produced from three colors: *red, green, and blue*. These are called the *primary colors*. Any two colors which, when combined, produce the sensation of white are called complementary colors (for example, red and greenish-blue).

Cones and Light. When the image of a well-lighted object falls on the fovea or the part of the retina immediately surrounding it, all the spectral colors of the light emitted by the object can be distinguished. The cones in this area are especially adapted for responding to light of all wave lengths. In areas a short distance from the fovea, yellows and blues can be distinguished, but not reds and greens. In the extreme peripheral regions of the retina, color sensations are not elicited, but only light and shades. Color discrimination is correlated to the distribution of the cones in the retina, the cones being most numerous in the fovea, absent in the peripheral regions.

Color Blindness. Color blindness is the inability to distinguish between colors. The condition may exist in a mild degree (*color weakness*) or it may be complete (*achromatism*). The latter state, in which the retina is totally insensitive to color, is very rare and is believed to be due to absence of cones. *Dichromatic* color vision is the condition

in which the subject is blind to red or green. A color-blind individual may be unaware of his visual defect until tested and informed of the result. One of the simplest of the tests devised to detect color-blindness is the *yarn test*, in which the subject is required to match yarns on the basis of their colors.

Color blindness is eight times more common in males than in females. It is inherited and sex-linked. Its mode of transmission is similar to that of hemophilia.

AFTER-IMAGES. The sensation of light persists for a time much beyond the period during which the stimulus is applied. If, for example, one looks at a bright light for a moment and then closes the eyes or turns them toward a dark surface, the sensation of light will continue for a noticeable period, then gradually fade away. By the same token, if one looks at a bright-colored object and then looks at a dark surface, an image of the object in the same color will persist. Upon this phenomenon is based the postulate that visual sensations are continuous, although visual stimuli may be intermittent. It is the principle underlying the technic of motion pictures, which consist of still pictures projected with sufficient rapidity (16 per second) for the after-image of each picture to persist until the next picture is seen, with the resulting illusion of a continuous picture.

The length of time required for a light stimulus to evoke a sensation is extremely short. A light flash of adequate intensity can be distinguished, though it may persist for only 1/8,000,000 of a second. Positive after-images last only a fraction of a second.

If one looks at a *colored* object for a few seconds and then directs his eyes to a sheet of white paper, the image of the object will appear on the paper, but in the color that is complementary to the first; that is to say, if the object is yellow, the after-image will be seen in blue. This is called a *negative after-image*. Should the object be black, the negative after-image will be white (and vice versa).

When one looks at a green object for a protracted time and then at a red object, the color of the latter will be intensified; this phenomenon is called *successive contrast*.

Visual Acuity. The degree of sharpness or distinctness of vision is called *visual acuity*. It is measured either by (*a*) the smallness of an object that can be seen clearly at a standard distance, or (*b*) the greatest distance at which a standard-sized object can be seen clearly. A common type of test for visual acuity is that based on a prepared chart of test letters (*Snellen test*). The degree of acuity is indicated by fractions such as 20/20, 20/10, 20/40, which express the subject's visual acuity as compared with that of a normal individual. A *normal eye* is one by which block letters of an established size can be distinguished clearly at a distance of twenty feet.

Visual Acuity (Army Standard)

- 20/40 One-half normal. Subject must stand 10 feet from chart to read letters normally read at 20 feet.
- 20/30 One-third normal. Subject must stand one-third nearer to read letters.
- 20/20 Normal vision.
- 20/15 Better than normal. Subject can read letters at one-third greater distance than normal.
- 20/10 Twice normal. Subject can read letters at twice the normal distance.

Another, and in some respects more satisfactory, test of visual acuity is that in which the *Jensen grids* are used. The test involves the reading of a chart having grids appearing at different angles. This test is employed for individuals who have not learned to read and hence do not know the names of the letters. It also overcomes the objection that letters may differ in their legibility.

Visual acuity is greatest in the *fovea*, where only cones are present and where they are most concentrated. It decreases gradually toward the periphery of the retina. For an object to be seen in three dimensions, three separate receptors must be stimulated; a line may be seen when only two receptors are stimulated. The smallest discernible image on the fovea has a diameter of 0.004 mm. (4 microns). Images on the peripheral portions of the retina must be larger than this in order to be discerned.

Visual acuity varies greatly among individuals. The reason for this is not known, but it is suspected that differences in the structure of the retina and the susceptibility of the refractory media to disorder are the primary factors.

VISUAL FIELDS. That part of the outside world which is seen by one eye constitutes the *visual field* of the eye. In man, the visual fields of the two eyes overlap, with the result that most objects within the field of vision are seen by both eyes. This is termed *binocular vision*. The movements of the eyes are controlled reflexly and in such a manner that both eyes are directed toward the same object; there is, then, an image of the object formed in each eye. The places where these two images of a given object lie are called the *corresponding points* of the two retinas.

The term "visual field" is also used to describe the surface of the retina which is stimulated by light rays coming from the external visual field. The diagnosis of certain diseases of the retina and the optic pathways can be made by an analysis of changes that have occurred in the visual fields. This can be mapped with the aid of an instrument called a *perimeter*. The area of the visual field of each eye is re-

duced somewhat by the eyebrow, nose, and cheek, which prevent some light rays from entering the eye.

BINOCULAR OR STEREOSCOPIC VISION. The ability to judge distance or to recognize that an object has depth is due largely to binocular vision, which results in formation of two retinal images which are slightly dissimilar owing to the fact that the two eyes view the object from different angles. The two images give rise to impulses which in the brain are fused into a single composite image. The judgment of distance depends on the degree of convergence of the eyeballs; the nearer the object, the greater the degree of convergence.

Factors other than binocular vision are of importance in the estimation of depth or distance. They are:

1. *The size of the image on the visual field.* The nearer the object, the larger the image formed on the retina.

2. *The relative distinctness of detail.* In near objects, color, form, and fine details are apparent; in distant objects, these tend to become less distinct.

3. *Perspective.* Objects that are in straight lines extending away from the viewer (for example, railroad tracks) appear to come together in the distance. This effect is employed in subjective judgment of distance. In a drawing, the illusion of distance is created by introducing into objects lines that converge toward a point in the background.

4. *Parallax.* This is the apparent relative movement of adjacent objects owing to change in the observer's position. As one moves forward, near objects appear to move in the opposite direction and distant objects in the same direction. In finer perceptions (as in the reading of a thermometer and many other scales), the same effect is produced by mere movement of the head or of the eyes. Because the eyes are more or less constantly in motion, the resulting parallax is highly useful in depth perception.

5. *Blocking out of distant objects by near objects.* Regardless of their relative sizes, near objects can block out distant objects. A coin held close to the eyes can block out a huge building several hundred feet away. Judgment of the nearness of the coin and the distance of the building depends on prior knowledge of the comparative true sizes of these objects.

VISUAL PATHWAY. The visual pathway includes those structures through which visual impulses pass in their course from the sensory receptors to the sensory areas of the brain. From the rods and cones, impulses are transmitted through bipolar neurons to ganglion cells whose cell bodies lie in the retina and whose axons leave the eye through the optic nerve. The axons pass through the *optic chiasma*, a crossing of the optic nerves, some fibers crossing to the opposite side, others remaining uncrossed (*semidecussation*). On passing through

the optic chiasma, the fibers, now constituting the *optic tract*, enter the brain and end in the *lateral geniculate body* of the thalamus. Here they synapse with neurons whose axons pass through the *internal capsule* to the *visual centers*, located in the cortex of the occipital lobes of the cerebrum. The nerve fibers that pass from the lateral geniculate body to the occipital cortex are called the *optic radiation*. In traveling from the rods and cones to the occipital cortex, a nerve impulse must pass through *three neurons*. The first has its cell body in the inner nuclear layer of the retina; the second is the ganglion cell of the retina; the third is a neuron with its cell body in the thalamus.

The visual field of each eye is divided into two regions: the *medial* or *nasal* half and the *lateral* or *temporal* half. For each eye, light rays from an object in the nasal half of the visual field fall on the temporal half of the retina; those from objects in the temporal half of the visual field fall on the nasal half of the retina. It should be noted that in the optic chiasma the nerve fibers from the nasal halves of the retinas *cross* and continue on to the thalamus; the nerve fibers from the temporal halves of the retinas *do not cross* but continue directly to the thalamus. In this way the visual center in the occipital cortex on each side receives impulses from the nasal half of the retina of one eye and the temporal half of the retina of the other eye. Accordingly, a lesion or injury to the *retina* or the *optic nerve* of one eye results in interference with (or loss of) vision in *one eye only*, but owing to the peculiar course of the nerve fibers in the optic pathway, a lesion or injury to the nerve fibers in the *optic chiasma*, *optic tract*, *optic radiation*, or *visual center* of the cortex causes blindness in one half of *each retina*, a condition known as *hemianopsia* or half-blindness.

Blindness. Blindness is the loss of sight sensation. It may be partial or complete. It may involve one eye or both eyes, or parts of both eyes. Blindness may result from (a) loss of transparency of any of the refractory media; (b) disease, injury, or abnormalities of the retina; (c) disease, injury, or abnormalities of the optic pathway; and (d) lesions or malfunction of the visual centers of the brain.

LOSS OF TRANSPARENCY OF REFRACTING MEDIA. The parts most frequently involved in this form of blindness are the cornea and the crystalline lens.

The *cornea* may be affected by injury or disease which results in the development of new vascular tissue known as a *pannus*. Such a cornea is usually cloudy and has an uneven surface covered with a thin film of blood vessels; the film may cover a portion of the cornea or all of it. This condition is seen in trachoma, eczema, and granular conjunctivitis. Another form is gonorrheal conjunctivitis in new born infants (hence the required use of silver nitrate drops as a prophylactic measure).

Loss of transparency of the crystalline lens is known as *cataract*. It is due to degenerative changes occurring in the lens proteins, leading to opacity. A cataract usually begins in the center of the lens and proceeds peripherally to in-

volve the capsule. It is most common in older persons (senile cataract). The condition can be corrected by *needling* the lens (opening the lens capsule and permitting the aqueous humor to enter, with subsequent reabsorption of lens substance) or by completely removing the lens. In the latter instance, glasses must be prescribed to compensate for the loss of refractive power. Cataract may also be congenital, infantile, traumatic, or occupational. It is frequently seen in association with diabetes. Its incidence is high in tropical areas, where it is thought to be due to the effects of excessive exposure to ultraviolet rays.

Sometimes, minute semiopaque bodies are present in the vitreous body. Usually they are of no significance, but they can create a disturbance of vision, appearing as flying specks (*muscae volitantes*) when the eyes are closed or when the eyes are directed toward a clear space. These are caused by the pressure in the vitreous body of epithelial cells or remnants of embryonic structures which cast shadows upon the retina, causing visual sensations of this kind.

DISEASES, INJURIES, OR ABNORMALITIES OF THE RETINA. Injury to the optic nerve or the optic tract results in degeneration of the nerve cells of the retina and consequent blindness. Injury to the eyeball may cause the retina to become detached from the choroid coat.

Glaucoma is a common cause of blindness. In this condition, intraocular pressure (normally 25 mm. Hg.) increases markedly due to either (a) an increase in production of intraocular fluid or (b) blockage of the draining canal (of *Schlemm*) located at the angle of the anterior chamber. This leads to pathologic changes in the retina and the optic nerve. There are two types: *primary glaucoma*, of unknown cause, which is not preceded by other ocular disease; and *secondary glaucoma*, which follows some other eye disease.

DISEASE, INJURY, OR ABNORMALITIES OF THE OPTIC PATHWAY. If a lesion involves the optic nerve, blindness of the corresponding eye results. If a lesion involves the nerve fibers between the optic chiasma and the occipital cortex, partial blindness of both eyes results; this is due to the decussation of some of the fibers in the optic chiasma. Brain tumors that involve the optic pathway may cause blindness.

LESIONS OR MALFUNCTION OF THE VISUAL CENTER OF THE BRAIN. Lesions from blows, fractures, brain tumors, and other causes, may involve the visual center in the occipital lobe. If the lesion is unilateral, partial blindness results, involving the halves of the eyes corresponding to the side of the injury; if bilateral, total blindness is the consequence.

Miscellaneous Disorders of Vision. There are innumerable visual disorders, including the following common defects.

PSYCHIC BLINDNESS. In this condition the individual sees but fails to recognize what he sees. Such disturbance of the visual sense is common in migraine headaches and in poisonings from wood alcohol.

SNOW BLINDNESS. The cause is excessive exposure to the glare of the sun light on snow. The condition is usually temporary.

NIGHT BLINDNESS. (See page 161.)

COLOR BLINDNESS. (See page 164.)

SCOTOMA. An island-like blind spot appears in the visual field; it may be temporary or permanent. It may follow excessive use of alcohol or tobacco, or overexposure to light. It usually accompanies migraine. Scotoma may arise

from an injured or diseased retina or from conditions involving the optic tract or the brain.

TUNNEL VISION. A concentric narrowing of the field of vision makes the external world appear as seen through a tunnel. Vision is so restricted as to require gross movements of the head and the eyes. Its cause is unknown. This condition is a common symptom of hysteria.

DIPLOPIA (DOUBLE VISION). In this condition, the optical axes of the two eyes cannot be directed simultaneously at the same object. It is also called *strabismus* or *squint*. In diplopia, the light rays from the object do not fall on corresponding points of the two retinas, giving rise to double images. (See page 157.)

EXOPHTHALMOS. Abnormal protrusion of the eyeballs may be caused by abnormal deposition of fat behind the eyeball or a widening of the palpebral fissure. The condition is a common symptom of hyperthyroidism.

ENDOPHTHALMOS. Recession of the eyeball into the orbit is due to absorption of orbital fat, occurring in emaciation from malnutrition, disease, or old age.

NYSTAGMUS. Involuntary to-and-fro movements (quickly forward, slowly backward) of the eyes occurring during, or following, rotation of the head.

STYE (HORDEOLUM). An inflammation of a sebaceous gland in the edge of the eyelid.

CHALAZION. A cyst or small, hard tumor that develops on the eyelid and is formed by a distention of the tarsal or Meibomian glands.

CONJUNCTIVITIS. Inflammation of the conjunctiva, the membrane which lines the eyelids and is reflected over the anterior surface of the eyeball.

TRACHOMA. Contagious granular conjunctivitis. It is chronic in nature and causes the formation of granular lids. It may lead to deformities of the eyelids with resultant visual disability or even blindness.

BLEPHARITIS. Inflammation of the eyelids, especially their edges; it involves the hair follicles and the glands of the lids.

ULCERS. Ulcers may occur on the cornea and are commonly the result of injury to or section of the trigeminal nerve. Because this nerve contains sensory fibers that are involved in eye reflexes, the presence of foreign bodies may not be detected or protective mechanisms brought into play to prevent injury to the cornea.

Practical Considerations

Eye Examination. Many pathologic conditions not associated with the eyes or the visual sense can be diagnosed through examination of the eyes. This is accomplished with the ophthalmoscope. Blood vessels of the retina can be clearly seen, and changes in them are symptomatic of certain diseases. The condition of the optic disc (the point where the optic nerve enters the retina) is also of importance. Excessive internal pressure, as in glaucoma, causes this disc to be pushed backward and to have a "cupped" appearance; excessive external pressure, as from a brain tumor, causes it to be pushed forward, creating the condition known as *choked disc*.

Drugs Affecting the Pupil. A *mydriatic* is a drug which *dilates* the pupil; examples are atropine, epinephrine, and cocaine. A *miotic* is a drug which *constricts* the pupil; examples are pilocarpine, physostigmine, and morphine. The pin-point pupil that is characteristic of morphine addiction is well known.

THE SENSATIONS OF HEARING AND EQUILIBRIUM

The sensation of hearing (the *auditory sense*) and that of equilibrium (the *labyrinthine sense*) are presented under an inclusive heading because of their close *anatomic* association. Although the external and middle ears are concerned exclusively with hearing, parts of the internal ear (especially the membranous labyrinth, hence "labyrinthine sense") play a role in the sense of balance.

Structure of the Ear

The ear, sense organ of hearing and of equilibrium, consists of three divisions: the *external ear*, the *middle ear*, and the *internal ear*.

External Ear. The external ear comprises the *pinna* and the *external acoustic (auditory) meatus*.

The *pinna* or *auricle* is the projecting portion located on the side of the head. It consists of a supporting cartilage and six poorly developed *intrinsic muscles* covered by skin. The rim of the ear is called the *helix*; the lower portion, the *lobe*. The elastic cartilage of the pinna is continuous with that of the external auditory meatus. Three small ligaments and three small *extrinsic muscles* serve to attach the ear to the head.

The *external acoustic meatus* is a canal about one inch in length which leads from the pinna to the middle ear. It has an outer *cartilaginous portion* and an inner *osseous portion*. The skin of the cartilaginous portion is thick and contains many fine hairs and sebaceous glands; the latter are lacking in the osseous portion. Also present are tubular *ceruminous glands*, which secrete *cerumen* or *ear wax*. These are modified sweat glands. The hairs and the wax prevent the entrance of foreign substances or insects into the ear.

Middle Ear. The middle ear includes the *tympanic membrane*, the *tympanic cavity* and the *auditory ossicles* enclosed by it, the *tympanic antrum*, and the *auditory tube*.

TYMPANIC MEMBRANE. Also called the *drum membrane*, this thin, semitransparent membrane forms a partition between the external auditory meatus and the tympanic cavity. It is somewhat elliptical in shape, measuring 9 to 10 mm. in length at its greatest diameter. Its external surface is slightly concave, owing to the pull exerted on it by the malleus (one of the ear bones), which is attached to its inner surface.

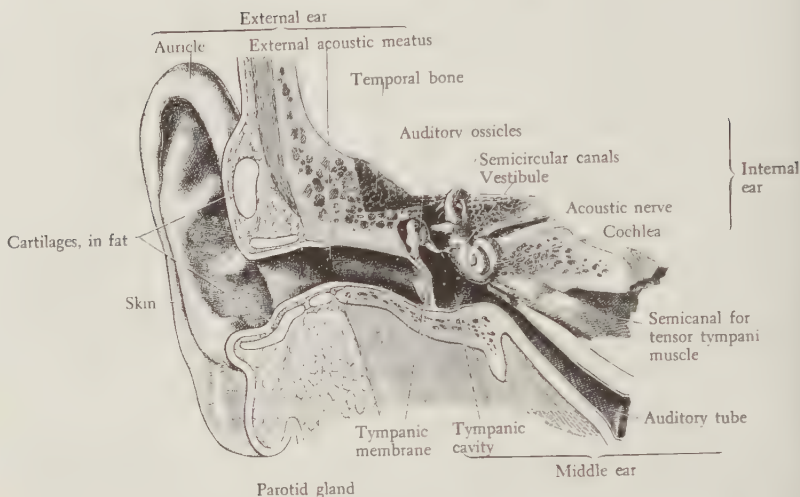


Fig. 5-6. Right ear, anterior half removed. (Reprinted with permission of Blakiston Division, McGraw-Hill Book Company, from *Morris' Human Anatomy*, 11th ed., edited by J. P. Schaeffer, 1953.)

TYMPANIC CAVITY. Commonly referred to as the *eardrum*, and also called simply the *tympanum*, this small air-filled cavity is located within the petrous portion of the temporal bone. It occupies the space between the external ear and the internal ear. The tympanic cavity communicates with the pharynx by means of the auditory tube. It is lined with mucous membrane, which also covers the surfaces of the ossicles and the two tympanic membranes. The epithelium of the middle ear is continuous with the epithelium of the pharynx by way of the auditory tube and with that of the mastoid cells by way of the tympanic antrum. This explains why respiratory infections frequently involve the middle ear and may spread to the mastoid cells, giving rise to mastoiditis.

AUDITORY TUBE. Better known as the *Eustachian tube*, the pharyngotympanic (or auditory) tube consists of an *osseous portion* contained within the temporal bone and a *cartilaginous portion* opening into the nasopharynx. This tube is lined with mucous membrane which is continuous with that of the pharynx and the middle ear. The auditory tube opens and closes with swallowing and yawning movements, which action equalizes the air pressure on the two sides of the tympanic membrane.

AUDITORY OSSICLES. Extending across the tympanic cavity there is a series of three small bones, the *auditory ossicles*. Named for their shape, they are the *malleus* ("hammer"), the *incus* ("anvil"), and

the *stapes* ("stirrup"). The malleus is attached to the tympanic membrane, and its head articulates with the base of the anvil. A process of the anvil articulates with the stirrup, the footplate of which lies in a small oval opening, the *fenestra vestibuli*, located on the median wall of the tympanic cavity. The joints between these ossicles are diarthrodial joints with synovial cavities. Two small muscles act on the ossicles. The *tensor tympani* is attached to the malleus and serves to tighten the tympanic membrane; the *stapedius*, the smallest skeletal muscle of the body, acts on the stapes.

Directly below the *fenestra vestibuli* there is a smaller opening, the *fenestra cochleae*, which is closed by a thin membrane, the *secondary tympanic membrane*. The *fenestra vestibuli* and the *fenestra cochleae* connect the middle ear to the vestibule of the inner ear.

TYMPANIC ANTRUM. An irregular chamber about the size of a small bean, the tympanic antrum is connected with the upper part of the *epitympanic recess* or *attic*. Into it open numerous *mastoid cells*, small irregular spaces which honeycomb the mastoid portion of the temporal bone. They vary greatly in number in individuals.

Internal Ear. The internal ear consists of a complicated series of canals located within the petrous portion of the temporal bone and containing the *sensory receptors for the senses of hearing and equilibrium*. Because the inner ear consists of complex communicating passages, the term *labyrinth* is applied to it. It is divided into two parts: the *osseous* ("bony") *labyrinth* and the *membranous labyrinth*.

OSSEOUS LABYRINTH. When the osseous labyrinth is dissected away from the surrounding bone, it can be seen to consist of three regions: the *vestibule*, the *semicircular canals*, and the *cochlea*. The osseous labyrinth is lined with a thin layer of periosteum and contains a fluid, the *perilymph*, which surrounds the membranous labyrinth; the membranous is enclosed within the osseous labyrinth.

The *vestibule* is the ovoid central portion. Extending upward and posteriorly from it are the three *semicircular canals*, each of which forms a curved arc lying in a plane approximately at right angles with the other two. On the basis of their position, they are designated *superior*, *posterior*, and *lateral canals*. They open into the vestibule by five openings. One end of each canal is enlarged to form an *ampulla*.

Opening from the anterior surface and lying in front of the vestibule is the *cochlea*, so named for its resemblance to a snail's shell. It consists of a spiral canal about 30 mm. in length, which turns about two and one-quarter times around a short, conical bony structure, the *modiolus*. Projecting upward from the modiolus, a thin bony plate, the *spiral lamina*, extends about halfway into the cochlea, dividing the cochlear canal into two passageways, namely, an upper *scala vestibuli* and a lower *scala tympani*. These two *scalae* join at the *apex* or *cupula*

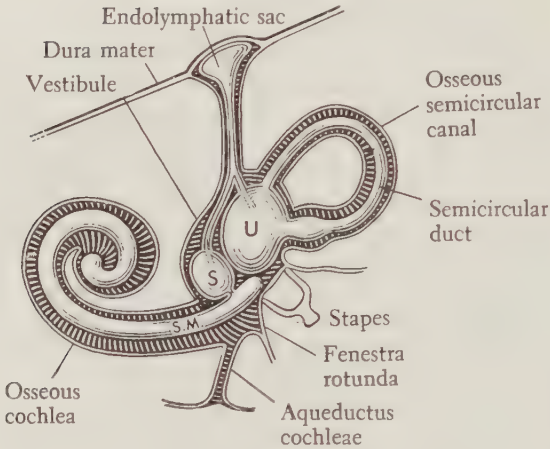


Fig. 5-7. Diagram of membranous labyrinth of inner ear enclosed in the bony labyrinth. S, saccule; U, utricle; S.M., scala media. (Reprinted with permission of The Macmillan Company from Kimber et al., *A Textbook of Anatomy and Physiology*, 13th ed., 1955.)

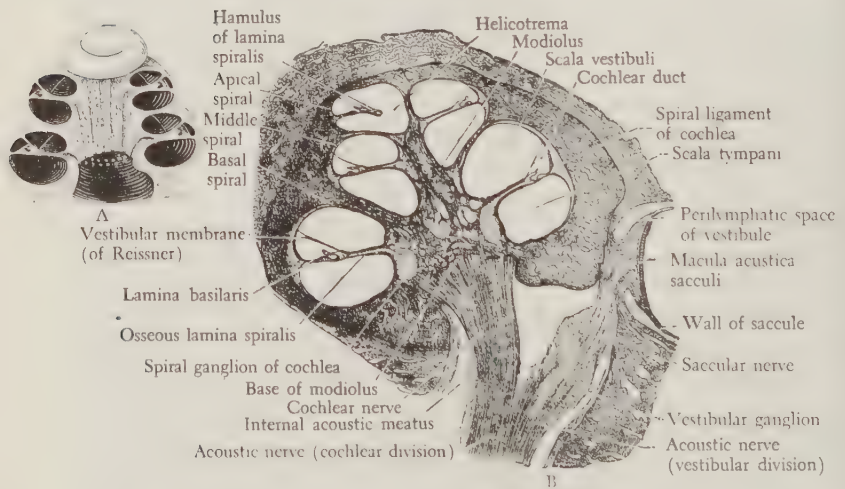


Fig. 5-8. Axial section through cochlea. (Reprinted with permission of Blakiston Division, McGraw-Hill Book Company, from Morris' *Human Anatomy*, 11th ed., edited by J. P. Schaeffer, 1953.)

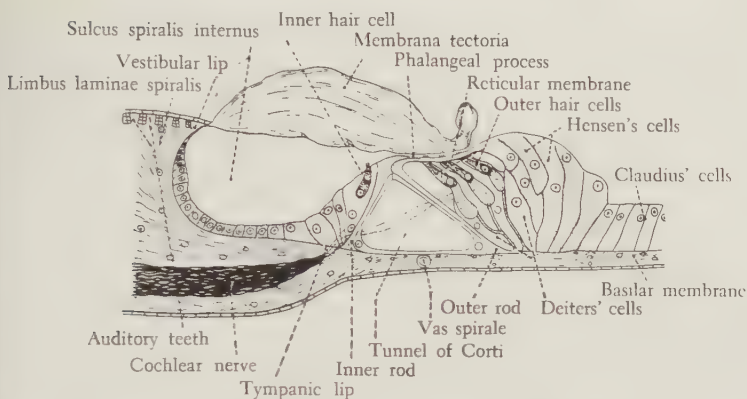


Fig. 5-9. Details of organ of Corti. (Reprinted with permission of St. Martin's Press and The Macmillan Company, Ltd. from Hamilton, *Textbook of Human Anatomy*, 1956.)

of the cochlea. The *base* of the cochlea adjoins the medial wall of the vestibule, into which the scala vestibuli opens. The scala tympani ends at the fenestra cochleae. The perilymph of the vestibule is continuous with that of the scala vestibuli.

MEMBRANOUS LABYRINTH. The membranous labyrinth is a series of interconnected sacs and tubes lying within the bony labyrinth. Although it is smaller than the bony labyrinth, it has the same general form. The space between these labyrinths is filled with perilymph except where fibrous bands connect them. The membranous labyrinth is lined with epithelium and contains a fluid, the *endolymph*.

Within the bony cochlea and the semicircular canals of the osseous labyrinth lie the cochlear duct (*scala media*) and the semicircular ducts, which have almost identical shapes. Within the vestibule, the membranous portion is divided into two sacs (the *utricle* and the *sacculle*) which are connected with each other by a small duct. From the posterior wall of the utricle extend the semicircular ducts, each of which has an *ampulla*. The sacculle is slightly smaller than the utricle, to which it is attached. From its anterior surface extends the cochlear duct. Also connected with the sacculle is a small, short *endolymphatic duct*, ending blindly in the *endolymphatic sac*.

An axial section of the cochlea reveals its detailed structure. Five sections are seen, each composed of three canals, the scala vestibuli, the scala tympani, and, lying between them, the cochlear duct. An *osseous spiral lamina* and *basilar membrane* separate the scala tympani from the cochlear duct and scala vestibuli; the *vestibular membrane* (of Reissner) separates the cochlear duct from the scala vestibuli. In the floor of the cochlear duct is the *spiral organ* (*organ of Corti*)

which, together with the basilar membrane (on which it rests), constitutes the essential organ of hearing.

The spiral organ consists of *hair cells* and *supporting cells*. The hair cells are short cylindrical cells, each of which bears a number of non-motile cilia (hairs) at its free end. Their basal ends are in contact with the fibers of the auditory nerve. Projecting over and in contact with the hair cells is a shelf-like structure, the *tectorial membrane*, a structure of jelly-like consistency. In the basilar membrane extending from the base to the apex of the cochlea are found the *auditory strings* or *basilar fibers*. Varying in length, they are shortest in the base, longest in the apex; their length increases progressively from base to apex. They number about 24,000.

The Auditory Pathway. The *cochlear branch* of the *acoustic* (8th cranial) *nerve* is the nerve of hearing. Along with the vestibular branch of the same nerve, it enters the temporal bone from the cranial cavity through the *internal acoustic meatus*. Its fibers are axons of neurons of the *spiral ganglion*, which lies in the spiral canal of the modiolus. Peripheral fibers pass from the spiral ganglion through the spiral lamina to the hair cells of the organ of Corti. They end as minute filaments about their bases. Central fibers from the spiral ganglion pass in the cochlear nerve to the medulla, where they synapse with nerve cells in the *cochlear nuclei*. Secondary neurons pass to the *medial geniculate bodies* of the midbrain and synapse with tertiary neurons, whose fibers terminate in the auditory centers in the temporal lobes of the cerebral cortex.

Physiology of Hearing

Hearing is the process by which the energy of sound waves is transmitted to the auditory receptors, producing the sensation of sound and ultimately the identification of particular sounds.

Steps in Hearing. The steps in the process of hearing are as follows:

1. Sound waves are directed by the pinna into the external auditory meatus.
2. The tympanic membrane is set in motion by the vibrations of the sound waves.
3. The auditory ossicles, acting as a series of levers which decrease the amplitude of the waves, transmit the vibrations across the middle ear to the fenestra vestibuli.
4. Movements of the footplate of the stapes at the fenestra vestibuli set up vibrations in the perilymph of the scala vestibuli, within the cochlea. Through the vestibular membrane, these vibrations are transmitted to the endolymph of the cochlear duct; through the basilar membrane, they are conducted to the perilymph of the scala vestibuli. Or the vibrations may pass up the scala vestibuli to the apex of the

cochlea and then down the scala tympani. In either case the vibrations are dissipated when they strike the membrane of the fenestra cochleae.

5. In some manner the mechanical vibrations act as a stimulus to the hair cells in the organ of Corti, and auditory impulses are initiated which are transmitted to the brain over the cochlear branch of the acoustic nerve.

Theories of Hearing. Sound waves have their origin in a vibrating body, such as, for example, a musical instrument, human vocal cords, metal striking against metal, and the sound-producing parts of insects. These vibrations vary in *amplitude* and *frequency*. Sound has three qualities which can be perceived by the human ear: pitch, loudness, and quality. *Pitch* depends on the frequency of vibrations. The human ear is capable of hearing sounds ranging in frequency from 16 to 20,000 double vibrations per second. Sounds of greater or fewer vibrations (higher or lower frequency) are inaudible. *Loudness* depends on the amplitude of the vibrations. The *quality* (or "timbre") of a sound depends on the *overtones* which are produced along with the fundamental tones. "Noise" is sound produced by fundamental pitch complicated by irregularities in the sound waves.

The mechanism by which variations in frequency of sound waves striking the ear are converted into nervous impulses which the brain interprets as differences in pitch is not known with certainty. Two theories have been proposed to account for this; they are the *resonance theory* and the *telephone theory*.

The *resonance theory* (*Helmholtz's theory*) postulates that the cochlea serves as an analyzer of sound. The basilar membrane, with its 24,000 fibers, is assumed to be a resonating structure. In much the same way that sound produced by a horn or the human voice near a piano will cause a string of the piano tuned to the same number of vibrations to vibrate ("sympathetic resonance"), so are the fibers of the basilar membrane thought to react to the vibrations of sound waves. Vibrations of different frequencies cause different regions of the basilar membrane to vibrate; the short fibers at the base respond to high frequencies, and the long ones at the apex respond to low frequencies. The hair cells in the organ of Corti overlying the fibers, which are set into sympathetic vibration, are stimulated, and impulses are carried to the brain, where they are interpreted.

The *telephone theory* postulates that the ear functions somewhat like a telephone system. The "transmitter" converts sound waves into electrical impulses of the same frequency. These impulses, when transmitted over a "wire," set up in the "receiver" vibrations which reproduce the original sound. In a similar way, it is believed that the basilar membrane vibrates as a whole and that the frequency of its

vibrations stimulates the hair cells, initiating impulses which, on reaching the auditory center, are interpreted and serve as the basis of pitch discrimination.

There is considerable evidence to support both theories, but there are many facts which both leave unexplained. The resonance theory is the more generally accepted. A modification of it, known as the *place theory*, postulates that in the auditory center of the cerebral cortex are located specific areas corresponding to points on the basilar membrane, and that stimulation of different areas of that membrane by sound vibrations is interpreted as differences in pitch.

Practical Considerations of Hearing

Hearing Acuity. Relative acuity of hearing can be tested by determining the distance at which a sound (such as the tick of a watch or the vibration of a tuning fork) can be heard from the subject's ear in comparison with a standard set for normal individuals. A more precise means is the *audiometer*, an instrument which produces electrical tones that can be altered in pitch and intensity (amplitude). Results are plotted on a graph, the record being called an *audiogram*.

Bone Conduction of Sound. The bones of the skull are capable of conducting sound vibrations to the inner ear which set the fluids of the cochlea in vibration, producing sound. To illustrate: If the external ears are plugged and the foot of a tuning fork is held against the skull or between the teeth, pronounced sound vibrations can be heard. Normally, however, most sound vibrations are conducted through the medium of air.

Localization of Sound. Like the sensation of sight, the sensation of sound is projected externally to the source of the stimulus. The ability to determine the exact source of a sound is, however, rather limited. When the sound waves strike both ears simultaneously, it is difficult to locate the source, but if the vibrations strike one ear before the other, the direction can be determined with fair accuracy. It is for this reason that one turns the head in order to hear more clearly. Ear disorders, especially those involving the cochlea, may give rise to ringing or buzzing sensations which are located within the affected ear.

Disorders of Hearing

Deafness. Deafness is the impairment, partial or complete, of the ability to hear sounds ordinarily heard by the average individual. There are three types of deafness: *transmission deafness*, *perception deafness*, and *central deafness*.

TRANSMISSION DEAFNESS. Any condition which interferes with or prevents the passage of sound waves through the external or middle ear brings about transmission deafness. Some common causes are: (a) presence of an obstruction in the external auditory meatus, (b) severe rupture of or abnormal thickening of the tympanic membrane, (c) inflammation of the middle ear (otitis

media) or destruction of its structures, (*d*) ankylosis (stiffness) of the auditory ossicles or fixation of the footplate of the stapes, and (*e*) blockage of the Eustachian tube, which may be temporary (from respiratory infections) or permanent (from adhesions or presence of adenoid tissue over the nasopharyngeal opening).

PERCEPTION DEAFNESS. This type of deafness results from conditions involving the cochlear structures or the auditory nerve. In this type of deafness, one may be deaf only to tones of high frequencies or those of low frequencies. It is sometimes seen as occupational deafness, occurring in persons working where there are very loud noises. This is a result of lesions involving the basilar membrane. Degeneration of cochlear and nerve structures, producing perception deafness, is common in advanced age.

CENTRAL DEAFNESS. Pathologic states of the auditory pathway or the auditory area of the cerebral cortex may give rise to central deafness. The causes include tumors, abscesses, injuries from blows or from skull fractures, and the effects of certain poisons.

OTHER DISORDERS. The following are common disorders of hearing.

Tinnitus. A ringing or buzzing sound which is subjective in origin is referred to as tinnitus. It may be due to impacted wax, otitis media, otosclerosis, or the effects of certain drugs (quinine, for example).

Otitis. Inflammation of the ear is designated in accordance with the part of the ear in which it is located: otitis externa, otitis media, otitis interna. Inflammation of the middle ear is the commonest of these conditions.

Otosclerosis. When the bone tissue around the fenestra cochleae and the fenestra vestibuli becomes converted into spongy bone (that is, becomes "sclerosed"), the stapes usually becomes fixed to the latter, and chronic progressive deafness ensues.

"Cauliflower Ear." An enlarged and grossly disfigured ear commonly seen in boxers and wrestlers, called "cauliflower ear," develops from bloody tumors (hematomata) between the perichondrium and the cartilage of the pinna.

Structure and Functions of the Apparatus of Equilibrium

The *semicircular ducts*, *utricle*, and *saccul*e are the sense organs of equilibrium and position. The utricle, into which the semicircular ducts open, and the saccule lie within the vestibule. These sense organs function in the maintenance of equilibrium and the coordination of body movements. They also provide awareness of the position of the body in space. It must be recognized, however, that other senses (sight, touch, muscle sense) assist in these functions.

Functions of the Semicircular Ducts. The semicircular ducts are filled with endolymph. In the ampulla, a dilated portion of each duct, there is a small elevation, the *crista*. Each *crista* consists of a group of hair cells covered by a mass of gelatinous material called a *cupula*. The hair cells are the sensory receptors.

Movement of the head brings about a movement of the endolymph. This stimulates the hair cells, and impulses are initiated which pass over the vestibular branch of the auditory nerve. The semicircular

ducts are the sense organs of *dynamic equilibrium* and are primarily involved in righting reflexes. Stimulation of the semicircular ducts also causes movements of the eyes, as in the condition known as *nystagmus*, wherein to-and-fro movements of the eyes occur when a person is rotated. These movements continue after cessation of a rapid rotary movement.

Rapid rotary movement for a sustained period of time will result in the sensation of dizziness and impairment of the ability to walk steadily. This is due to stimulation of the horizontal canals. The effect is more pronounced when the vertical canals, too, are stimulated.

Functions of the Utricle and the Sacculæ. The utricle and the sacculæ each contain within their walls areas of sensory neuro-epithelium called the *macula utriculi* and *macula sacculi*. These maculae are oval structures measuring about 2 by 3 mm. Their epithelium contains two types of cells: *sustentacular* or *supporting cells* and *hair cells*. Over the surface of the maculae there is a gelatinous layer, the *otolithic membrane*, into which the hairs of the hair cells penetrate. In the upper portion of the "jelly" are found many minute crystalline bodies called *otoliths* or *otoconia*, which are made up of calcium carbonate and a protein.

Changes in position of the head or the body cause movement of the otoliths, which stimulate the hair cells, thus initiating nerve impulses. These impulses are then transmitted to the brain through the vestibular branch of the acoustic nerve. The utricle and the sacculæ are the sense organs of *static equilibrium*. They are essential for the maintenance of posture and for certain types of equilibrium reactions, namely, the righting and attitudinal reflexes.

The Labyrinthine Pathway. The ampullae of the semicircular ducts and the maculae of the utricle and the sacculæ are innervated by the superior and inferior divisions of the *vestibular nerve*, a branch of the acoustic nerve. Fibers of these nerves are dendrites or peripheral processes of neurons whose cell bodies lie in the vestibular ganglion that is located in the internal auditory meatus of the temporal bone. Central processes of these neurons pass through the auditory nerve to reflex centers of the medulla and the cerebellum. The cortical connections of the vestibular nerve fibers have not yet been definitely determined.

Disorders of the Labyrinthine Sense. Disorders of the sense of equilibrium are vertigo, dizziness, and motion sickness.

VERTIGO. The sensation that the outside world is revolving about the subject is called *objective vertigo*; the associated sensation that one is revolving in space is called *subjective vertigo*. Use of this term as a synonym for dizziness is erroneous. Vertigo may result from disease of the inner ear (*Ménière's dis-*

ease); cardiac, gastric, or ocular disturbance; brain lesions; and toxemia, as in Bright's disease.

DIZZINESS. This is the sensation of unsteadiness with a feeling of movement within the head. Also called "giddiness."

MOTION SICKNESS. A feeling of malaise, the principal feature of which is nausea, arises from the effects of motion created by various means of transportation. The susceptibility of individuals varies greatly, but the cause is the same: stimulation of the vertical canals. The condition is variously referred to as *seasickness*, *airsickness*, *carsickness*, *trainsickness*, et cetera.

6: THE ENDOCRINE SYSTEM

The regulation and correlation of body activities are accomplished in two ways: (1) through nervous impulses conducted by the nervous system, and (2) through chemical substances or *hormones* carried by the blood and lymph. The organs which secrete hormones are called *endocrine glands* or glands of internal secretion. Collectively, these glands comprise the *endocrine system*. In this system are found: the hypophysis cerebri (pituitary body), thyroid gland, parathyroid glands, adrenal glands, pancreas, duodenum, testes, ovaries, and placenta. Sometimes the thymus gland and the pineal body are regarded as belonging to the endocrine system, but as yet there is no conclusive evidence that they secrete hormones which have a regulatory effect.

Endocrine glands are ductless, their secretions being discharged into the blood or lymph, by which they are transported to all parts of the body. In this respect they are differentiated from *exocrine* glands, such as salivary or sweat glands, whose products are discharged through ducts which open onto a surface.

HORMONES

A *hormone* is a chemical substance produced by an organ or tissue, which has a specific effect on tissues that are more or less remote from its place of origin. Sometimes this effect is of a general nature, affecting the body as a whole; in other instances, the effects are much more limited and specific. Internal secretions or *endocrines* may have either an excitatory or an inhibitory effect. Originally, the term "hormone" (literally, *to excite*) was applied only to those having excitatory effects, whereas those having inhibitory effects were called "chalones." The latter term, however, was not generally adopted, and the term "hormone" has come to be applied to any internal secretion regardless of whether its effects are excitatory or inhibitory.

Methods of Studying Hormones. Endocrinology is of comparatively recent origin. Indeed, it was 1902 before the term "hormone" was first used in connection with *secretin*, a substance secreted by the duodenum which stimulates pancreatic secretion. Most present-day knowledge about hormones has been acquired since 1920. Five principal methods are utilized in the study of endocrine glands.

1. *Experimental Removal.* In this way an organ can be identified as having an endocrine function if (a) its removal or inactivation (e.g.,

by irradiation) in either immature or mature animals produces observable or measurable changes in structure or function, and (b) these conditions disappear upon the administration of an extract containing the active principle obtained from normal glands or upon successful transplantation of glandular tissue.

2. *Injection Method.* By this means the effects of injection of the active principle of the gland in normal animals are observed.

3. *Clinical Method.* By clinical observation a determination is made of the correlation between body dysfunction and disorders of glands.

4. *Analytic Method.* Tests are utilized to determine the presence or absence of hormones in blood, urine, saliva, or body tissues.

5. *Tracer Method.* Radioactive tracer elements are used to locate and to follow the course of endocrine substances in the body.

Factors Controlling the Secretion of Hormones. Two principal classes of factors which regulate the secretion of hormones by endocrine glands are: nervous factors and chemical factors.

NERVOUS FACTORS. Some endocrine tissues are innervated by the autonomic nervous system, and their activity is controlled by nerve impulses which may either stimulate or inhibit glandular secretion. The adrenal medulla receives fibers from the sympathetic division of this system; the secretion of epinephrine increases or decreases with the system's activity. Nerve impulses from the hypothalamus influence the activity of the hypophysis.

CHEMICAL FACTORS. Chemical substances carried by the blood are of primary importance in the regulation of the secretory activity of endocrine glands. These substances may be hormones produced by other glands or they may be nonhormonal substances. The secretory activity of the thyroid gland, the adrenal cortex, and the gonads is dependent upon *hormones* secreted by the hypophysis. In turn, the secretion of the hypophysis is influenced by hormones produced by the gonads. The production of insulin by the islets of Langerhans in the pancreas is dependent primarily on the blood sugar level. An increase in blood sugar increases secretory activity; a decrease diminishes it. The presence of fatty or acid substances in the duodenum induces the secretion of *secretin* by the duodenal mucosa.

Nature of Hormones and Their Action. All hormones are organic compounds. Some are relatively simple in structure and have been analyzed and synthesized (for example, epinephrine from the adrenal medulla). Others are extremely complex; in some cases, their structure is still unknown. Some hormones, in particular those produced by the testes, ovaries, and the adrenal cortex, are steroids, a group of compounds including the sterols. It is thought that in the body these are derived from cholesterol. All the others are nitrogen compounds and show characteristics of being protein in nature.

Hormones are potent substances. Very minute amounts injected into the blood stream of an animal may produce marked effects. For example, the injection of 0.001 mg. of epinephrine (adrenalin) into a cat is capable of producing noticeable effects on the heart and the blood vessels.

The way in which hormones produce their effects is not known. Because minute quantities produce pronounced effects, it was first believed that they acted as catalysts in a manner similar to that of some enzymes, but the evidence seems to negate this point of view. Nevertheless, it has been shown that under certain conditions enzyme action is considerably altered by the presence of specific hormones. This has given rise to the theory that the *effects* of hormone activity are largely mediated through their effects on the enzyme systems in the body.

It is generally agreed, however, that the fundamental physiological processes of the body are under hormonal control; growth, development, maturation, and reproduction are among them. Furthermore, the rates of various physiological processes, their rhythmic variations, the rate of energy expenditure—in short, the basic life processes—all are regulated by hormones. These substances also have a profound effect on the functioning of the nervous system. Much of a person's behavior and most of the traits which, collectively, constitute personality are dependent upon the normal functioning of the endocrine glands.

HYPOPHYSIS CEREBRI

The hypophysis cerebri or *pituitary body* (also called "pituitary gland") is a rounded body attached to the base of the brain by a thin *infundibular stalk*—a downward extension of the floor of the third ventricle. It lies in the sella turcica of the sphenoid bone. The hypophysis averages $1.3 \times 1.0 \times 0.5$ cm. and weighs about 0.5 gm.

Gross Structure of the Hypophysis. The hypophysis consists of two primary portions: an *anterior (glandular) lobe* and a *posterior (neural) lobe*. These portions have different embryonic origins. The anterior lobe develops from an evagination (*Rathke's pouch*) of the ectoderm of the primitive mouth or stomodeum. The main portion of the posterior lobe develops as a downgrowth of the diencephalon. In about the fourth week of embryonic life, Rathke's pouch fuses with the posterior portion and loses its connection with the buccal cavity. The principal parts of the hypophysis cerebri are shown as follows:

| | | | | |
|----------------|---|---------------------------------|---|---------------------------------|
| Anterior lobe | { | Pars tuberalis Pars distalis | { | (arising from Rathke's pouch) |
| Posterior lobe | { | Pars intermedia Pars nervosa | { | (arising from the diencephalon) |

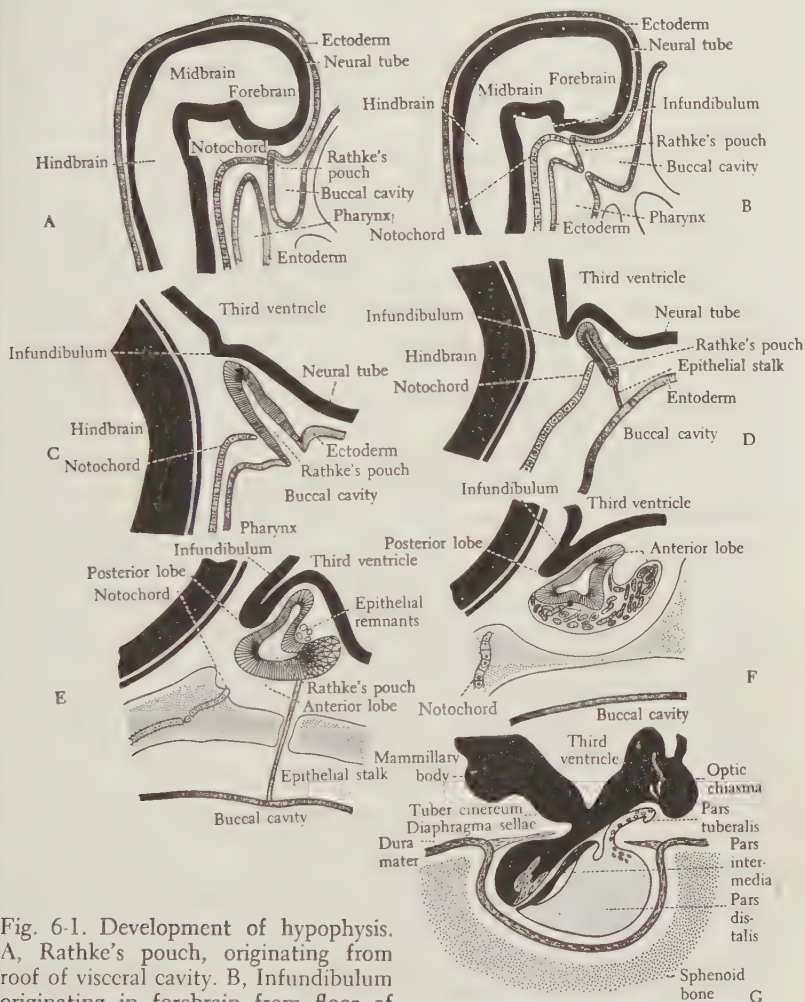
The Hypophysis

Fig. 6-1. Development of hypophysis. A, Rathke's pouch, originating from roof of visceral cavity. B, Infundibulum originating in forebrain from floor of third ventricle. C, Rathke's pouch fully developed, opening as craniobuccal duct into buccal cavity. D, Rathke's pouch now a closed epithelial sac. Epithelial stalk still connects it with the buccal cavity. E, Residual epithelial stalk traversing the sphenoid bone is still present. F, Epithelial stalk has disappeared. Anterior lobe undergoes differentiation. G, Relationship of hypophysis (adult) to adjacent structures. (After J. H. Globus.) (Reprinted with permission of Blakiston Division, McGraw-Hill Book Company, from *Morris' Human Anatomy*, 11th ed., edited by J. P. Schaeffer, 1953.)

Microscopic Structure of the Hypophysis. The anterior lobe of the hypophysis consists chiefly of columns of epithelial cells of two types: *chromophil* cells having alpha and beta cells which differ in staining reactions; and *chromophobe* cells, also called "chief cells" or "reserve cells." The *posterior neural lobe* consists of branching cells called *pituicytes* which are modified neuroglia cells (astrocytes), and of unmyelinated nerve fibers from cells located in nuclei of the hypothalamus.

General Function of the Hypophysis. The secretions of the *anterior lobe* control skeletal growth, growth and development of the gonads, maturation of the reproductive cells, secretion of milk by the mammary glands, as well as functional activities of the thyroid, the islets of Langerhans, the adrenal cortex, and possibly the parathyroids. The secretions of the *posterior lobe* influence blood pressure through their effects on smooth muscle tissue in the blood vessels. They have a stimulating effect on smooth muscles of the uterus, especially in late stages of pregnancy. They also have an antidiuretic effect on the kidneys.

In addition to the foregoing functions, the hypophysis influences a number of other physiologic processes, presumably through hormonal control although specific hormones for such activities have not yet been identified. Among these processes are those which involve the metabolism of fats and carbohydrates.

Hormones Secreted by the Hypophysis. The hormones secreted by the two lobes of the pituitary body are specific and clearly differentiated in function for each of the lobes.

ANTERIOR LOBE HORMONES. The anterior lobe of the hypophysis secretes a number of hormones, among which the following have been definitely identified:

1. Growth hormone (somatotrophin, STH).
2. Thyroid-stimulating hormone (thyrotrophin, TSH).
3. Gonad-stimulating hormones (gonadotrophins):
 - (a) Follicle-stimulating hormone (FSH).
 - (b) Luteinizing or interstitial cell-stimulating hormone (LH or ICSH).
 - (c) Luteotrophic hormone (LTH).
(Prolactin or lactogenic hormone)
4. Adrenocorticotrophic hormone (ACTH).

Growth Hormone. This hormone of the hypophysis regulates growth, in particular that of the skeleton. Hyposecretion before puberty results in dwarfism; hypersecretion causes generalized overgrowth or gigantism. Following puberty, excessive secretion results in acromegaly, a condition in which renewal of growth takes place and the bones of the hands, feet, and face become markedly overdeveloped.

Thyrotrophic Hormone. This hormone regulates the development

and functioning of the thyroid gland. Hyposecretion results in atrophy; hypersecretion in hypertrophy and hyperplasia of the thyroid epithelium.

Gonadotrophic Hormones. These hormones are essential for the normal development and functioning of both the primary and accessory sex organs. The *follicle-stimulating hormone* (FSH) is essential for development of ovarian follicles, maturation of the ova, and secretion of estrogenic hormones. In the male, FSH stimulates the germinal epithelium of the seminiferous tubules. A *luteinizing hormone* (LH), also called *interstitial cell-stimulating hormone* (ICSH), stimulates development of the corpus luteum in the female and production of its hormone, *progesterone*. It increases the effects of FSH. In the male, LH (ICSH) stimulates development of interstitial cells of the testis and secretion of testicular androgen (testosterone).

Reciprocal relations exist between the hypophysis and the ovaries. During the first part of the menstrual cycle, secretion of FSH by the hypophysis induces growth and development of the follicle and secretion of estrogenic hormones. When these reach a certain concentration, the production of FSH is inhibited. Then the LH of the hypophysis, acting together with the FSH, causes the ovum to emerge through the ovarian wall. The cells of the empty follicle, under the action of LH, proliferate to form the corpus luteum. The corpus luteum produces estrogen after ovulation, under the stimulus of LH. Organization of the corpus luteum into, and its maintenance as, a temporary endocrine gland with its own unique hormonal secretion is not, however, achieved until the development of a third gonadotrophic hormone of the hypophysis, *luteotrophin* (LTH). It is the reorganizing action of the luteotrophin on the corpus luteum that causes this temporary gland to secrete progesterone, which, in turn, acts on the hypophysis to inhibit further secretion of LH. Progesterone prepares the uterine endometrium for pregnancy.

Lactogenic Hormone. This hormone, called *prolactin* (which has been found to be luteotrophin) initiates the secretion of milk by the mammary glands, though it apparently plays no role in the development and differentiation of these glands. During pregnancy, milk secretion is prevented by the inhibiting action of estrogenic hormones on prolactin. At birth, however, with the passing of the placenta, estrogen levels fall, and milk secretion begins under the stimulus of prolactin.

Adrenocorticotrophic Hormone. This hormone is essential for the normal development and functional activity of the adrenal cortex. It stimulates the production of cortisone and other adrenocortical hormones. Under conditions of stress, such as starvation, excessive physical activity, extremely high or low temperatures, and certain disease

states, the adrenals hypertrophy owing to increased output of ACTH.

POSTERIOR LOBE HORMONES. Extracts from the posterior lobe of the hypophysis have been shown to contain two hormones: vasopressin (antidiuretic hormone or ADH) and oxytocin.

Vasopressin. This hormone, also called *pitressin*, has vasopressor and antidiuretic effects and contracts the intestine. It is produced by the hypothalamus and passes by way of supraoptico-hypophyseal tracts to the hypophysis where it is stored. It acts on smooth muscle of blood vessels, inducing constriction with resulting rise in blood pressure. It also acts on the kidney, increasing reabsorption of water (*anti-diuresis*) and decreasing the reabsorption of salts.

Oxytocin. Oxytocin acts directly on the uterus, inducing vigorous contractions (*oxytotic effect*), especially in late stages of pregnancy. It also acts on myoepithelial tissue of mammary glands, stimulating milk ejection.

THYROID GLAND

The thyroid gland is a bilobed structure lying in the midportion of the neck, just anterior to the upper portion of the trachea and slightly below the larynx. Each of its two lobes, connected across the midline by a narrow isthmus, is about $5 \times 3 \times 2$ cm. The entire gland averages about 30 gm. in weight. The size and structure of the thyroid

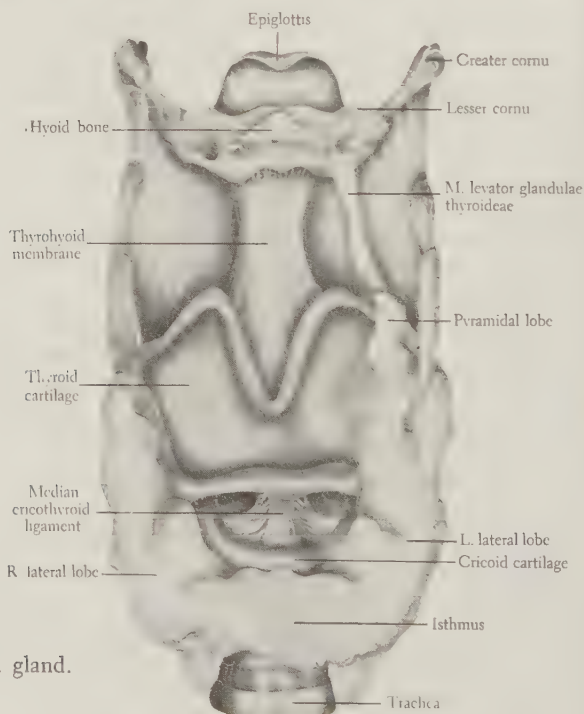


Fig. 6-2. Thyroid gland.

gland are, however, extremely variable; it responds to a large number of influences, among them age, sex, body temperature, and diet. The iodine content of the diet plays a dominant role. The gland tends to be slightly larger in females; during pregnancy its size increases.

Microscopic Structure of the Thyroid. The thyroid gland consists of a large number of closed, spherical or ovoid vesicles called *follicles*, surrounded by a fibrous capsule which is continuous with the cervical fascia. Each follicle is lined with a single layer of cuboidal or low columnar epithelial cells and encloses a homogeneous, gelatinous substance called *colloid*. This substance is high in iodine content and contains, in storage form, the active principle secreted by the gland.

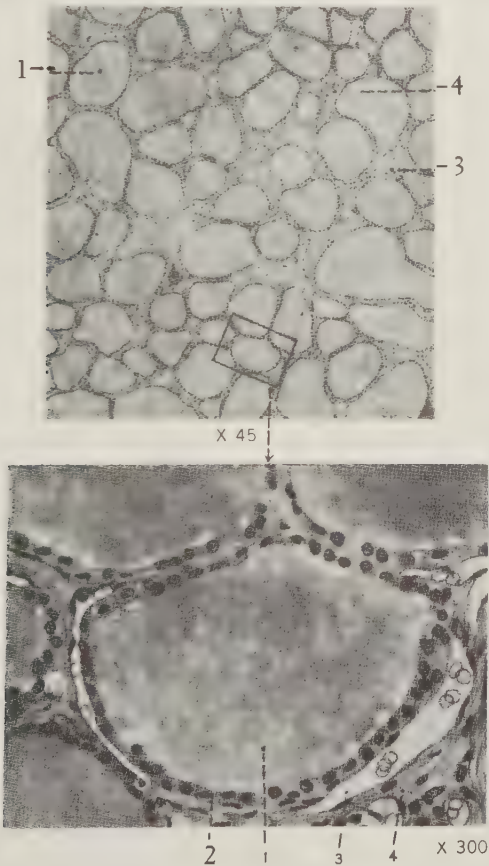


Fig. 6-3. Section through thyroid. (1) Follicle containing colloid. (2) Cuboidal follicular epithelium. (3) Blood vessel. (4) Intercellular connective tissue. (From *Atlas of Human Anatomy*, Barnes & Noble, Inc., 1959.)

Blood and Lymphatic Supply of the Thyroid. The thyroid gland is a highly vascular organ, receiving its blood supply from two *superior thyroid arteries* (branches of the external carotid) and two *inferior thyroid arteries* (branches of the subclavian arteries). An inconstant artery, the *thyroidea ima*, from the brachiocephalic artery, when present appears to compensate for absence or for deficiency in one or the other thyroid artery. In proportion to its size, and with the possible exception of the adrenals, more blood flows through this gland than through any other organ of the body.

From the thyroid gland the blood drains into the *superior, middle, and inferior thyroid veins*, which empty into the *internal jugular and brachiocephalic veins*. The gland is well supplied with *lymphatic vessels*, which drain into the main lymph ducts.

Nerve Supply of the Thyroid. This gland receives sympathetic fibers from the superior and inferior sympathetic ganglia. Parasympathetic (vagal) fibers also innervate the gland. The fibers end principally in the walls of the blood vessels and are vasomotor in their effect. Whether secretory fibers exist is not certain. The thyroid gland has the ability to secrete even if its normal nerve supply is interrupted or if it is transplanted to another site.

Embryonic Origin of the Thyroid. The thyroid gland is endodermal in origin, arising as a median ventral outgrowth of the floor of the pharynx. It grows caudally as a hollow tube, its distal end thickening and forming a solid mass of epithelium which differentiates into cords; these cords eventually give rise to the follicles. The connection with the pharynx disappears, though it sometimes persists as the *thyroglossal duct*. The foramen cecum at the base of the tongue indicates the point of embryonic origin.

Function of the Thyroid. The thyroid gland regulates through its hormones basal metabolism, that is, the rate of cellular oxidation and resulting heat production. An increase in the secretion of thyroid hormones increases the basal metabolic rate (BMR); a decrease in secretion lowers it. The thyroid gland also influences general body growth, ossification of bones, the development of teeth, muscle tone, body temperature, mental development, and the functional activity of the gonads and the adrenal glands.

Hormones of the Thyroid. Three iodine-containing compounds have been extracted from thyroid tissue. They are: *iodothyroglobulin*, *di-iodotyrosine*, and *thyroxin*. The first is believed to be the active agent or hormone of the thyroid gland; the other two substances are believed to be intermediate compounds involved in the synthesis of the first.

Practically all the iodine of the body (about 30 mg.) is found in the thyroid gland. About 40 per cent of the iodine present in this

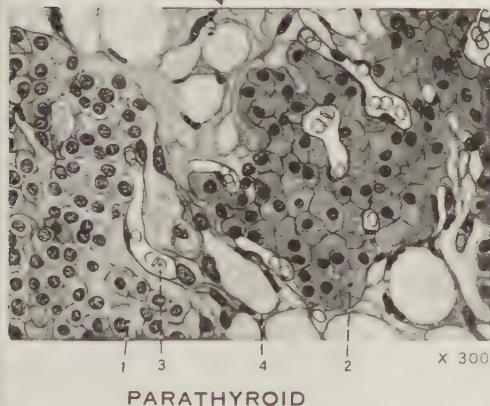
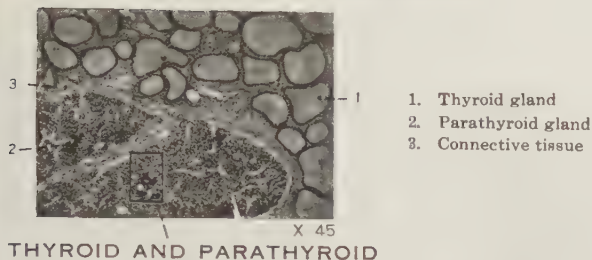


Fig. 6-4. Section through parathyroid. (From *Atlas of Human Anatomy*, Barnes & Noble, Inc., 1959.)

gland is in the thyroxin radical. This thyroxin portion stimulates the oxidative processes in the tissues of the body. Thyroxin is an amino acid having the formula $C_{15}H_{11}O_4NI_4$.

THE PARATHYROID GLANDS

The parathyroid glands, usually four in number, lie within the capsule of the thyroid gland. They are generally ovoid in shape and are found along the posterior median surfaces of each lobe of the thyroid gland. Each parathyroid averages 4×6 mm. in size and 0.035 gm. in weight.

Microscopic Structure of the Parathyroids. Each parathyroid gland consists of densely packed cells within a connective tissue framework of reticular fibers. Between the groups, capillaries and sinusoids form an anastomosing network. In some instances, the cells form compact masses; in others, they have a cord-like arrangement. Two types of cells are present: *principal* or *chief cells*, which have a clear, nongranular cytoplasm, and *oxyphil cells*, larger in size and containing granules

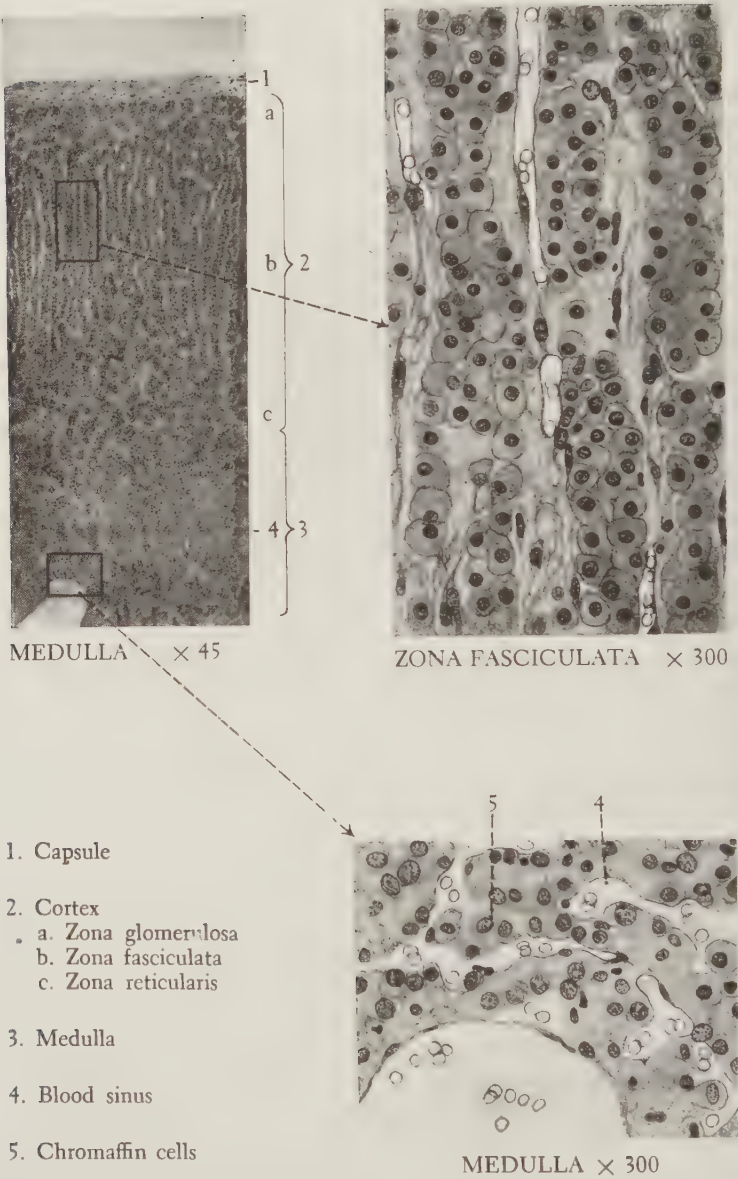


Fig. 6-5. Portion of adult adrenal. (From *Atlas of Human Anatomy*, Barnes & Noble, Inc., 1959.)

which stain with acid stains. The principal cells are regarded as the primary hormone-secreting cells.

Blood, Lymph, and Nerve Supply of the Parathyroids. The blood and nerve supply is the same as that of the thyroid gland. Lymphatic drainage is into the vessels that drain the thyroid.

Embryonic Origin of the Parathyroids. The parathyroids develop from dorsal portions of the third and fourth *pharyngeal pouches*. The fact that these pouches also give rise to the thymus gland probably accounts for the occasional presence of extra masses of parathyroid tissue in the connective tissue of the neck, near (or sometimes within) the thymus.

Function of the Parathyroids. These glands secrete the *parathyroid hormone* (PTH) which is concerned primarily with metabolism of calcium and phosphorus. Hypo- or hypersecretion results in changes in calcium-phosphorus ratio in the blood, with resulting disorders in the skeletal system and altered irritability of nervous and muscular tissues.

ADRENAL GLANDS

The adrenal (suprarenal) glands are two encapsulated, flattened bodies lying in contact with the superior medial surface of each kidney. They are roughly triangular in shape and somewhat variable in size, averaging 3 to 5 cm. in length, 4 cm. in width, and 5 cm. in thickness. Each weighs about 5 gm. Each consists of an external cortical portion, or *cortex*, and an inner medullary portion, the *medulla*. The outer portion of the cortex is bright-yellow in color; the inner portion is reddish-brown. The medulla is grayish.

Microscopic Structure of the Adrenals. The adrenal *cortex* consists of epithelial cells arranged in three zones: the outer *zona glomerulosa*, the middle *zona fasciculata*, and the inner *zona reticularis*. The cortical cells are arranged in more or less parallel cords perpendicular to the long axis of the capsule. The *medulla* consists largely of chromaffin cells forming irregular masses separated by sinusoidal vessels. Chromaffin cells stain brown when treated with chromic acid. Also present in the adrenal medulla are sympathetic ganglion cells, occurring singly or in groups.

Blood and Lymph Supply of the Adrenals. Both adrenals are highly vascularized. They receive blood through the *superior suprarenal artery* (a branch of the inferior phrenic artery), the *middle suprarenal artery* (a branch of the aorta), and the *inferior suprarenal artery* (a branch of the renal artery). Some of these arteries supply the capsule, some the cortex, while others pass through the cortex to the medulla, where they empty into sinusoids which form an anastomosing network. Blood is drained into the *central veins* of the medulla, which

lead to the *suprarenal vein*. On the right side, the suprarenal vein empties into the *inferior vena cava*; on the left side, it empties into the *left renal vein*.

Lymphatic vessels are present in the capsule and the medulla. They lead to vessels that drain into the lymph nodes along the abdominal aorta or into the mediastinal lymph nodes.

Nerve Supply of the Adrenals. The adrenal glands are innervated principally by autonomic fibers from the coeliac plexus of the sympathetic division. The fibers are preganglionic and pass without interruption through the splanchnic nerves to the capsules of the adrenals, where they form extensive plexuses. Branches from these plexuses pass through the cortex to the medulla, where they end in the walls of blood vessels, though some apparently end directly in medullary cells. Small ganglia and individual neurons are also present in the medulla of the adrenals. It is not definitely known whether these glands receive parasympathetic fibers.

Embryonic Origin of the Adrenals. The adrenal glands have a double origin. The cortex develops from the coelomic mesoderm in the immediate vicinity of the embryonic urogenital organs. The medulla develops from ectoderm. The chromaffin cells of the medulla are derived from neural crest cells, which also give rise to the ganglion cells of the sympathetic nervous system. These cells migrate into the primordium of the cortex and acquire a central position.

Function of the Adrenals. The adrenal glands play an important role in the regulation of many activities of the body. At present, however, knowledge of these functions is incomplete, though intensive research is being carried on to clarify the situation. Some of the known functions of the adrenals are:

CORTICAL FUNCTIONS. The adrenal cortex produces a number of hormones which are necessary for the maintenance of life. They play important roles in regulating salt metabolism, water-electrolyte balance, muscular activity, reproductive activity, and kidney function.

MEDULLARY FUNCTIONS. Through its hormone epinephrine, the adrenal medulla regulates basal metabolism and carbohydrate metabolism and initiates many physiologic responses which are similar to those brought about by stimulation of the sympathetic nerves (*sympathomimetic effect*).

Hormones of the Adrenals. From adrenal cortical extracts, some thirty-eight or more specific substances have been isolated; the most important ones are described here. The medullary hormones, epinephrine and norepinephrine, are also discussed here.

ADRENAL CORTICAL HORMONES. Hormones produced by the cortex of the adrenal gland fall into three groups: (1) *gluco-corticoids*, which are concerned principally with protein and carbohydrate metabolism;

(2) *mineralo-corticoids*, which influence electrolyte balance and water distribution in the tissues; and (3) a group of sex hormones, principally androgens. Among the steroid substances isolated, seven possess physiological activity. These are the glucocorticoids *cortisone* (Comp. E), *corticosterone* (Comp. B), *cortisol* (17-hydroxycorticosterone, hydrocortisone, or Comp. F), and *11-dehydrocortisterone* (Comp. A). Mineralo-corticoids include *11-desoxycortisterone* (DOC), *17-hydroxy-11-desoxycorticosterone* (Comp. S), and *aldosterone*. Aldosterone also possesses glucocorticoid properties. The functions of three cortical steroids are given below.

Cortisone. When it was first isolated from the adrenal cortex, this substance was known as Kendall's Compound E. In 1949, Dr. Philip Hench and his associates at the Mayo Clinic demonstrated that it has marked value in the treatment of rheumatoid arthritis. Since then, many other conditions have been found to respond favorably to its use, among them rheumatic fever, asthma, hay fever, and certain diseases involving lymphatic and myelogenic tissues. Cortisone has an inhibiting action on hyaluronidase, an enzyme which hydrolyzes hyaluronic acid. The latter is a substance widely distributed throughout the body where it serves to bind and hold cells together. Through its action on hyaluronidase, cortisone and other cortico-steroids inhibit the spread of inflammatory processes, especially in connective tissues.

Corticosterone. Along with its related compounds, this substance is responsible for absorption of glucose from the intestine, the formation of glycogen in the liver and in muscles, and utilization of carbohydrates by the body tissues. It also plays a role in fat and protein metabolism.

Desoxycorticosterone. This hormone is essential for normal water and salt metabolism. If the cortex is removed or if there is inadequate secretion, excessive loss of sodium and chloride ions and retention of potassium ions ensue. This is thought to be the result of defective renal tubular function. The permeability of capillaries is also altered, so that fluids which are normally held in the blood shift to intercellular spaces. Osmotic equilibrium is altered, and an imbalance in the distribution of ions and water results.

CORTICAL HORMONES AND RESISTANCE TO STRESS. Cortical hormones play an important role in bringing about physiological changes which enable the body to adapt to environmental changes which are likely to damage the body. Examples of such changes, which are referred to as "stresses," are extreme heat or cold, burns, excessive muscular activity, infections, toxins, and trauma. Animals which have been adrenalectomized or persons suffering from cortical insufficiency are extremely sensitive to the effects of such conditions. The injection of cortical extracts increases general bodily resistance and minimizes the effects of harmful stimuli.

ADRENAL MEDULLARY HORMONE. The hormone secreted by the medulla is *epinephrine*, a white, crystalline substance, $C_9H_{13}NO_3$, which darkens upon exposure to light. It has been synthesized. A second hormone, *norepinephrine*, has been found to be present in adrenal extracts. It resembles epinephrine in its chemical structure but produces slightly different physiological effects. Commercial epinephrine (adrenalin), is a mixture of the two hormones. When injected parenterally, epinephrine brings about marked physiologic changes. Some of its effects are:

1. *Immediate and pronounced rise in blood pressure.* This is brought about by an increase in rate and force of the heart beat and vasoconstriction of the arterioles, especially those of the skin and the kidneys. However, certain vessels are dilated, especially those supplying the skeletal muscles and the heart. The initial increase in rate of heart beat is followed by a decrease.

2. *Reduction in rate of respiration and temporary apnea.* This is followed by an increase in the rate and depth of respiration.

3. *Stimulation of skeletal muscles*, thus increasing capacity for work and decreasing fatigability.

4. *Increase in basal metabolic rate and rate of oxygen consumption.*

5. *Stimulation of carbohydrate metabolism.* Epinephrine stimulates the liver in the conversion of glycogen to glucose. Hypersecretion will increase blood sugar and will sometimes give rise to glycosuria.

6. *Other effects.* These include an increase in coagulability of blood; dilation of the pupils; stimulation of uterine contractions in labor; decrease in muscular tone of the gastrointestinal tract; and contraction of the arrector muscles which move the hair follicles.

The foregoing effects are in general the same as those produced by stimulation of the sympathetic division of the autonomic nervous system, for which reason this division and the adrenals are sometimes referred to collectively as the *sympatho-adrenal system*.

Secretion of epinephrine is increased under the following conditions: emotional states (such as fear, anger, worry), hemorrhage and asphyxia, hypoglycemia, and temperature changes.

"Emergency Theory." Because many of the changes induced by epinephrine enable the body better to meet situations encountered under conditions of stress, a so-called "emergency theory" has been advocated to explain its functional significance. Critical experiments have, however, failed to show that this hormone is essential for bringing defense mechanisms into play or even that its secretion is necessary in the normal activities of the organism.

Clinical Applications of Epinephrine. The hormone of the adrenal medulla is used clinically for the following purposes: as a heart and circulatory stimulant; to raise blood pressure; in the treatment of re-

spiratory disturbances, such as asthma, rhinitis, and hay fever; to reduce blood coagulation time; to reduce local congestion; to counteract insulin shock and resultant hypoglycemia; in conjunction with local anesthetics. For effects of norepinephrine, see page 127.

Regulation of Secretion of Epinephrine. The secretion of epinephrine by the adrenal medulla is under nervous control. Stimulation of the splanchnic nerves leading to the medulla results in the liberation of large quantities of this hormone. In normal bodily activity, nerve centers in the hypothalamus discharge impulses which regulate many visceral organs innervated by the sympathetic system. Experimental stimulation of the hypothalamus brings about responses similar to those resulting from the injection of epinephrine; these are, in general, the changes which usually occur under emotional stress. It is conjectured that these changes, initiated rapidly by nervous excitation, are prolonged by increased secretion of epinephrine.

PANCREAS (ISLETS OF LANGERHANS)

The pancreas is a double-functioning gland producing an exocrine secretion which is discharged into the duodenum and an endocrine secretion which is discharged into the blood stream.

Microscopic Structure of the Islets. The endocrine portion of the pancreas consists of isolated masses of cells, the *islets of Langerhans*,

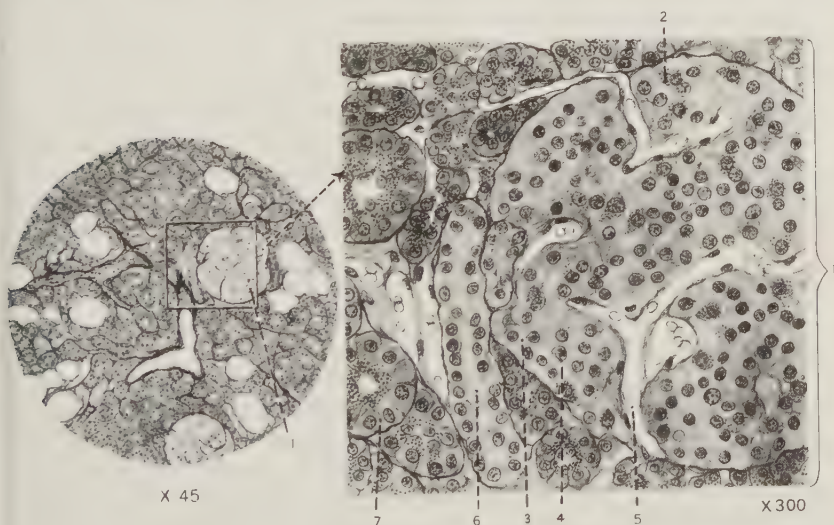


Fig. 6-6. Portion of pancreas. (1) Islet of Langerhans. (2) A cells. (3) B cells. (4) D cells. (5) Blood vessel. (6) Pancreatic duct. (7) Pancreatic acinar cells. (From *Atlas of Human Anatomy*, Barnes & Noble, Inc., 1959.)

which lie scattered through the pancreas. They vary in number from 200,000 to 1,800,000, being most numerous in the tail portion. The islets comprise irregular cords of prismatic cells. These cells lack secretory granules and stain lighter than the surrounding acinar tissue. Through a selective staining technic, three types of cells can be distinguished: alpha or "A" cells, beta or "B" cells, and "D" cells. The "B" cells contain small granules which are soluble in alcohol. They constitute the bulk of an islet and secrete insulin. "A" cells secrete glucagon.

Blood, Lymph, and Nerve Supply of the Pancreas. The pancreas receives blood through branches of the splenic, superior mesenteric, and hepatic arteries, and the blood is returned through the splenic and superior mesenteric veins to the portal vein. The islets are highly vascularized. *Lymphatic* vessels drain into the celiac nodes along the celiac artery. For *nervous innervation*, the pancreas receives sympathetic fibers from the coeliac plexus, and parasympathetic fibers from the vagus nerve. Sympathetic ganglion cells are present in the interlobular connective tissue.

Embryonic Origin of the Pancreas. The pancreas develops from the endoderm of the fore-gut in the region of the liver diverticulum. It arises as two portions: a dorsal and a ventral. The dorsal portion arises from the wall of the duodenum, the ventral from the embryonic bile duct. From the former, the tail, containing most of the islets, develops; the latter gives rise to the head portion, and its ducts become the functional pancreatic duct. The acini and the islets develop from anastomosing tubules which connect with the pancreatic duct, but the tubules connected with islets never become patent or functional.

Function of Pancreas. The pancreas, through its hormone, insulin, in conjunction with the hormones of other glands (adrenal cortex and medulla, thyroid, and hypophysis), regulates the metabolism of carbohydrates. This includes the utilization of glucose by the tissue cells, glycogen formation in the liver, and conversion of glycogen into glucose. Indirectly, the metabolism of fats and amino acids is influenced.

Hormones of the Pancreas. The principal hormone secreted by the islets of Langerhans is *insulin*. Potent extracts containing insulin were first prepared by Banting, Best, MacLeod, and Collip in 1922. The first crystalline insulin was prepared by Abel and his associates in 1927. Insulin is an extremely complex protein compound. Its empirical formula is $C_{45}H_{65}O_{14}N_{11}S$. It is obtained principally from the pancreatic tissue of cattle, though it has been extracted from pancreatic tissue of other animals. Insulin is used primarily in the treatment of diabetes mellitus (see pages 208 and 209).

Recently another hormone which has just the opposite effect of insulin (anti-insulin effect) has been isolated from crude insulin prepara-

tions. It is a *hyperglycemic-glycogenolytic factor* (HGF) called *glucagon*. It acts on the liver, bringing about the conversion of liver glycogen to glucose, thus increasing the blood sugar level. Its physiological significance is unknown.

DUODENUM

The duodenal mucosa elaborates several hormones which play an important role in the activities of the pancreas, liver, gallbladder, and stomach. When acid chyme containing fat enters the duodenum from the stomach, the mucosa is stimulated to secretory activity. Among the hormones produced by the duodenum are: secretin, pancreozymin, cholecystokinin, and enterogasterone.

Secretin. This hormone acts on the pancreas and brings about the secretion of pancreatic juice, especially increasing its water content. It also acts on the liver, increasing the flow of bile. The precise sources of secretin are not known.

Pancreozymin. This hormone, like secretin, stimulates pancreatic secretion, but it acts to increase the enzyme content of pancreatic juice, especially that of amylase, rather than the water content.

Cholecystokinin. This hormone acts on the gallbladder, bringing about the discharge of bile. It induces relaxation of the *sphincter of Oddi* in the bile duct and contraction of the muscles in the gallbladder, thus increasing the flow of bile into the intestines.

Enterogasterone. This hormone is produced especially when fats are present in the duodenum. It reduces muscular activity of the stomach and inhibits gastric secretion. Because it reduces the amount of acid in the stomach, it is sometimes called the "anti-ulcer" hormone.

A number of other substances considered to be hormonal in nature have been identified as having their origin in the intestinal mucosa. The evidence pertaining to them is, however, inadequate, and experimental results have in some cases proved too conflicting to merit including them at this time in the category of true hormones.

GONADS (TESTES AND OVARIES)

The gonads, both testes and ovaries, serve a double function: (1) the production of reproductive cells (sperm and ova), and (2) the production of hormones. Those hormones which bring about or stimulate the development of male characteristics are *androgens*; those which stimulate the development of female characteristics are *estrogens*.

The *structure, blood and lymph supply, and nervous innervation* of the testes and ovaries are discussed on pages 213–223.

Hormone of the Testes. The principal hormone produced by the testes is *testosterone*, a potent androgenic substance having the for-

mula $C_{19}H_{32}O_2$. It is a sterol and has been synthesized from cholesterol. Testosterone is employed clinically in the form of testosterone propionate. It is not definitely known which cells of the testis are concerned with the production of testosterone, but most of the evidence points to the interstitial tissue as the source. The interstitial cells (*cells of Leydig*) form compact masses occupying the angular spaces between the seminiferous tubules. They are irregular in shape and variable in size, and have large nuclei. Their cytoplasm contains a large, clear attraction sphere and numerous inclusions, the latter being characteristic of these cells.

FUNCTIONS OF TESTICULAR HORMONE. The hormone of the testes regulates the development of secondary sex characteristics, which appear in normal males at puberty. Among these are: growth of hair on the face and in the pubic and axillary regions, enlargement of the larynx and resulting deeper voice, development of male stature and form, development of accessory glands (prostate gland and seminal vessels), and emergence of sexual libido (sex drive).

The testicular hormone also regulates the growth and development of the penis and scrotum. In its absence, erection usually does not occur. The development of the epididymis and its functioning in the storage and maturation of spermatozoa are profoundly influenced by testosterone.

EFFECTS OF CASTRATION. Removal of the testes (castration) may be necessary owing to disease or injury; in some parts of the world, it is performed as a religious rite. If the testes are removed *before* puberty, secondary sex characteristics fail to develop; hair does not grow on the face, the voice remains highly pitched, and there tends to be an excess accumulation of adipose tissue. Skeletal development is also altered, with late ossification of epiphyses, bringing about an increase in the length of the long bones, especially those of the legs. If castration occurs *after* puberty, libido gradually lessens and disappears altogether, and there is a partial regression of the secondary sex characteristics and involution of the accessory sex glands. In the experimental castration of animals, similar changes are noted, but, if testicular tissue is implanted or testicular hormones are injected, the changes will not occur.

REGULATION OF SECRETION OF TESTICULAR HORMONES. Both the spermatogenic and the endocrine functions of the testes are under the control of the gonadotrophic hormones secreted by the hypophysis. These are the same gonadotrophins produced in females, namely, the follicle-stimulating hormone (FSH) which stimulates spermatogenesis, and the luteinizing hormone (LH or ICSH in the male) which stimulates development of interstitial cells of the testis and secretion of testicular androgens. There is no evidence of nervous regulation.

Androgenic Hormones. A large number of substances having androgenic properties have been obtained from body tissues or fluids, or have been prepared synthetically. Among them are:

- Testosterone (from beef testes)
- Adrenosterone (from beef adrenals)
- Andosterone (from male and female urine)
- Isoandrosterone (from male and female urine)
- Dehydro-isandrosterone (from male and female urine)
- Epi-allopreganol-3-one-20 (from pregnancy urine)

Hormonal Bisexuality. Both sexes secrete both male and female hormones. Normal women excrete androgens in their urine; the source of these androgens is either the ovaries or the adrenals. In males, the production of estrogenic hormones is also evidenced by their presence in urine; their source is not known but is believed to be the testes and the adrenals.

Hormones of the Ovaries. The ovaries are the principal source of female sex hormones, which are produced chiefly in two structures: the *ovarian (Graafian) follicle* and the *corpus luteum*. The Graafian follicle is a spherical mass of cells in which the ovum develops; when mature, it is a large vesicle 5 to 10 mm. in diameter, containing follicular liquor. The corpus luteum is a mass of cells developing within a ruptured Graafian follicle after ovulation has occurred.

ESTROGENS. These hormones are responsible for the sexual growth and development which take place at and after puberty. They are essential for the development of secondary sex characteristics, such as body form and mammary glands; in the adult, they are essential to the normal functioning of the genital system. They are concerned with cyclic changes in the uterus, in particular those during the first half of the menstrual cycle.

Extragenital Effects of Estrogens. In addition to producing the foregoing effects on the genital structures, estrogens bring about many extragenital changes such as changes involving body form, condition of the skin, and mucous membranes, structure of the skeleton, and water balance and various other metabolic activities. They are also primarily responsible for the development and maintenance of sexual libido.

The Principal Estrogens. Several estrogenic substances have been identified in the body tissues or fluids, and a number of these have been synthesized. The principal ones in the body are *estradiol*, *estrone*, and *estriol*. It is believed that estradiol is the primary hormone and that estrone and estriol are derivatives of it. All three have been isolated from the placenta and from the urine of pregnant women. Most of the evidence indicates that estradiol is formed principally by the follicular cells of the Graafian follicles of the ovary, although it may

be secreted by the corpus luteum, placenta, adrenal cortex, and testis.

Experimental Observations. Most of the experimental data on estrogenic hormones have come from studies of their effects on the estrous cycles of rodents. In immature females or in castrated adult females the estrous cycle fails to occur and vaginal changes (determined by examination of vaginal smears) do not occur. Injection of estrogenic substances brings about estrous and correlated changes in the reproductive organs of such females, especially the uterus and the vagina.

Chemical Composition of Estrogens. All estrogens are steroids and are similar in structure to the testicular and adrenal cortical hormones, which are also steroids. Estradiol is the most potent of them, being four to eight times more effective than estrone, which, in turn, is about ten times more effective than estriol. However, it should be noted that the potency of hormones varies greatly, depending on the method of administration and the conditions under which they are administered.

Effects of Menopause on Estrogen Production. The cessation of ovarian function (menopause) brings on a wide range of adjustments of the body which are described briefly on pages 229-230 of this volume. With particular reference to the hormones, it is known that estrogens may continue to be produced for some time even though follicular activity has ceased. The adrenal glands are probably the source of postmenstrual estrogens, which continue to be excreted in the urine. The structural and functional changes that occur throughout the body during the menopause are largely consequences of reduced hormonal production.

PROGESTERONE. This hormone is produced by the corpus luteum, which develops after the rupture of the Graafian follicle at the time of ovulation.

Functions of Progesterone. Progesterone supplements the action of the estrogens and is responsible for changes in the uterine mucosa or endometrium during the second half of the menstrual cycle. Under its influence, the glands of the uterus develop and secrete, and the endometrium becomes prepared to receive the fertilized ovum. If no ovum is fertilized, the corpus luteum degenerates, there is a reduction in the amount of progesterone secreted, and, in the absence of its influence, the endometrium regresses, portions undergo necrosis, and small hemorrhages occur. The discharge of portions of the endometrium together with non-coagulating blood constitutes menstruation. On the other hand, if the ovum is fertilized, the corpus luteum persists. Under the influence of progesterone, the endometrium is sensitized, and, when the blastocyst enters the uterus, implantation occurs and the decidual

membranes develop. The nourishment and early development of the embryo depend on the continued action of progesterone. During pregnancy, progesterone brings about enlargement of the mammary glands by stimulating the development and differentiation of the secretory acini.

Chemical Composition of Progesterone. Progesterone is a steroid and is closely related chemically to the estrogens and androgens. It has been prepared synthetically. Progesterone is used clinically in cases of threatened abortion because it tends to reduce contractions of the uterine musculature and to control bleeding.

REGULATION OF SECRETION OF OVARIAN HORMONES. The secretion of ovarian hormones is regulated by pituitary gonadotrophins. The follicle-stimulating hormone (FSH) induces development of the follicle and secretion of estrogens; the luteinizing hormone (LH), acting synergistically with FSH, stimulates estrogen secretion and development of corpus luteum; luteotrophin (LTH) maintains the corpus luteum and stimulates secretion of progesterone.

PLACENTA

During pregnancy the placenta secretes a number of hormones, namely, chorionic gonadotrophin, estrogens, and progesterone. *Chorionic gonadotrophin* is a substance similar to the anterior pituitary gonadotrophins, but differs from them in certain physiologic and chemical aspects. It appears in the blood and urine of women within two weeks after ovulation, for which reason its presence serves as confirmation of pregnancy (through such tests as the Ascheim-Zondek and Friedman tests). Its concentration increases until the second month, after which it declines to a low level, which is maintained until after parturition.

It is believed that this hormone is produced by cells covering the chorionic villi. It causes the corpus luteum to develop and persist, and acts to inhibit estrogen production. Therapeutically, chorionic gonadotrophin is used to bring about the descent of the testes in cases of *cryptorchism*, which indicates that it may function in a similar way in the development of the male fetus. When injected into males, it stimulates the interstitial cells, increasing androgen production. In females, the amount of estrogens in the urine increases during pregnancy, then disappears after parturition. This, together with the facts that follicles are not developing in the ovary and that, in a pregnant woman, estrogens are present in the urine even after removal of the ovaries, suggests that there is an extra-ovarian source of estrogens, namely, the placenta. It is evident, then, that during pregnancy the placenta takes over or supplements the endocrine functions of the ovary.

A TABULAR SUMMARY OF THE PRINCIPAL ENDOCRINE GLANDS

(Hormones They Secrete, and Functions)

| GLANDS | HORMONES SECRETED | FUNCTIONS |
|---|-----------------------------------|--|
| <i>Hypophysis Cerebri</i> | | |
| Anterior lobe | growth hormone | regulates growth |
| | thyrotrophic | regulates thyroid activity |
| | gonadotrophic | regulates activity of testes and ovary |
| | lactogenic | regulates secretion by mam- mary gland |
| | adrenocorticotrophic | regulates activity of adrenal cortex |
| Posterior lobe | vasopressin | contracts blood vessels inhibits diuresis |
| | oxytocin | induces uterine contractions |
| <i>Thyroid</i> | iodothyroglobulin | regulates metabolic rate (thyroxin) |
| <i>Parathyroids</i> | parathormone | regulates calcium and phos- phorus metabolism |
| <i>Adrenals</i> | | |
| Cortex | cortisone | all are involved in salt and |
| | corticosterone | carbohydrate metabolism, |
| | desoxycorticosterone | and in regulation of water balance |
| Medulla | epinephrine (adrenalin) | regulates organs under con- norepinephrine trol of the sympathetic division of the autonomic nervous system |
| <i>Pancreas</i> (Islets of Langerhans) | insulin | regulate organs under con- |
| | glucogen | tabolism, especially func- tions of utilization and storage |
| <i>Duodenal mucosa</i> | secretin | stimulates secretion of pan- creatic juice and bile |
| | pancreozymin | stimulates secretion of pan- creatic juice |
| | cholecystokinin | regulates contraction of gall- bladder |
| | enterogasterone | regulates gastric secretion and motility |

A TABULAR SUMMARY OF THE PRINCIPAL ENDOCRINE GLANDS (Cont.)

| GLANDS | HORMONES SECRETED | FUNCTIONS |
|------------------|----------------------------------|--|
| <i>Testis</i> | androgens (testosterone) | regulate the development and functioning of male accessory sex organs, development of secondary sex characteristics; influences libido |
| <i>Ovary</i> | | |
| Ovarian follicle | estrogens | regulate the development and functioning of female accessory sex organs, development of secondary sex characteristics; influences libido |
| Corpus luteum | progesterone | supplements estrogens in regulation of accessory sex organs, prepares uterus for implantation, stimulates development of alveoli of mammary glands |
| <i>Placenta</i> | chorionic gonadotrophin .. | essential for persistence and development of corpora lutea; in urine, forms basis for pregnancy tests |
| | estrogens and progesterone | same as for ovarian estrogens and progesterone |

DYSFUNCTION OF ENDOCRINE GLANDS

Dysfunction of an endocrine gland is usually manifested in one of the following ways: hyposecretion or hypersecretion.

Hyposecretion, or hypofunctioning, is characterized by an absence of (or a marked diminution in the amount of) hormone secreted. The effects noted are similar to those encountered in the experimental removal of the gland.

Hypersecretion, or hyperfunctioning, is characterized by an excessive secretion of the hormone. The effects noted are similar to those observed following injection of excessive quantities of the hormone in normal animals.

Hyposecretion and hypersecretion may each be of structural or of functional origin. Structural changes resulting from atrophy, hypertrophy, or hyperplasia of glandular tissue or from the development of cysts or of tumors may result in glandular dysfunction. Functional disturbances usually involve disorders in nervous or chemical control of glandular activity.

The following are some of the common disorders or pathological conditions resulting from dysfunction of some of the endocrine glands.

| <i>Gland</i> | <i>Hyposecretion</i> | <i>Hypersecretion</i> |
|------------------------------------|--|--|
| Thyroid | Simple goiter Cretinism Myxedema (Gull's disease) | Exophthalmic goiter (Graves disease) Toxic goiter |
| Hypophysis Anterior lobe | Dwarfism Pituitary cachexia (Simmond's disease) | Acromegaly Gigantism Pituitary basophilism |
| Posterior lobe | Diabetes insipidis | |
| Parathyroid | Tetany | Osteitis fibrosa |
| Adrenal Cortex | Addison's disease | Sexual precocity Virilism Cushing's syndrome Adrenogenital syndrome |
| Pancreas (Islets of Langerhans) | Diabetes mellitus | Hyperinsulinism |
| Gonads (Ovaries and testes) | Failure of sexual differentiation and maturation | |

Simple Goiter. Enlargement of the thyroid is frequently due to inadequate intake of iodine, as indicated by the incidence of the type of goiter and the lack of iodine in the soil. Other causes may include inflammation from infection and specific goiter-producing substances in certain foods.

Cretinism. This condition of retarded physical and mental growth results from imperfect development or early atrophy of the thyroid. It is characterized by dwarfism, subnormal body activities (lowered temperature, lower metabolic rate, slower pulse), thickened skin, and retardation in mental development and in sexual maturation.

Myxedema (Gull's Disease). In the adult, hypofunctioning of the thyroid may cause myxedema, a condition characterized by a subnormal metabolic rate, retarded nervous activity, coarsened and rounded features and thickened nostrils, roughened skin, and loss of hair. Lethargy and obesity are common symptoms.

Exophthalmic Goiter (Graves Disease). This condition is caused by hypertrophy and hyperplasia of the thyroid tissue resulting in excessive production of thyroid hormones. It is characterized by a marked increase in metabolic rate, muscular weakness, rapid heart beat, shortness of breath, and nervous disturbances such as tremors. Exophthalmos (protrusion of the eyeballs) is a common symptom. The follicles of the thyroid become irregular in form

and the secretory epithelium becomes folded. The gland may increase to the extent of interfering with respiration and deglutition.

Toxic Goiter (Adenomatous Goiter). This condition is attributed to a neoplasm involving the secreting portion of the thyroid. It is characterized by the presence of capsulated or nonencapsulated masses of hyperplastic thyroid tissue. Symptoms are similar to those of exophthalmic goiter except for the absence of exophthalmos and a less marked increase in basal metabolism.

Dwarfism, Pituitary Cachexia, Acromegaly, Gigantism. Dwarfism and pituitary cachexia (Simmond's disease) are associated with hyposecretion, acromegaly and gigantism with hypersecretion, of the anterior lobe of the hypophysis. (See discussion on pages 186-187.)

Diabetes Insipidus. This condition, associated with dysfunctioning of the posterior lobe (especially the pars nervosa) of the hypophysis is characterized by excessive loss of body fluids by a great increase in the amount of urine (which, however, contains no sugar) and by polydipsia (excessive thirst). The activity of the pars nervosa is regulated by nerve impulses from the hypothalamus.

Tetany. Hyposecretion of the parathyroid glands causes a rapid drop in the concentration of calcium in the blood plasma. The resulting condition, tetany, is characterized by intermittent tonic muscle spasms, muscle cramps, and hyperirritability of both the central and the peripheral divisions of the nervous system. Hypoparathyroidism may occur spontaneously, or it may follow removal of the parathyroid glands. The symptoms are relieved by injection of calcium or parathyroid hormone.

Osteitis Fibrosa (von Recklinghausen's Disease). Hyperplasia of parathyroid tissue may cause hypersecretion of the parathyroids, as in the case of gland tumors. The accompanying increase in blood calcium and withdrawal of calcium from the bones may lead to extensive changes in bone structure and to the deposit of calcium in the soft tissues, especially the kidneys. The condition is characterized by skeletal deformities, diminished neuromuscular irritability, loss of muscle tone, and the development of difficulties of movement.

Addison's Disease. (Chronic Adrenal Insufficiency). This disease involves atrophy and degeneration of the adrenal cortex, resulting in extreme muscular debility, fatigue, gastrointestinal disturbances, low blood pressure, nervous impairment, reduced basal metabolism, and (frequently) a remarkable pigmentation of the skin, most apparent in normally pigmented areas as well as on exposed parts such as the face and hands.

Sexual Precocity, Virilism, Cushing's Syndrome, Adrenogenital Syndrome. Tumors involving cortical tissue may cause hyperfunctioning of the adrenal cortex, accompanied by disturbances in functions of the sex organs and changes in sexual characteristics. In fetal life or early childhood sexual precocity may result. In the female at later stages of maturity manifestations include enlargement of the clitoris, growth of pubic and facial hair, deepening of the voice, atrophy of the sex organs, and cessation of menstruation. The cortical changes involved occur most frequently at adolescence and during the menopause, with development of male secondary characteristics and the regression

of female characteristics. Hyperfunctioning of the adrenal cortex in males is associated with precocious development of male accessory organs and secondary sexual characteristics, but not the gonads.

Diabetes Mellitus. This condition, the commonest form of diabetes, is caused by the failure of the islets of Langerhans to secrete adequate amounts of insulin (hypoinsulinism). The symptoms indicate disturbances in sugar metabolism, especially in the ability of the tissues to utilize glucose. There is a marked rise in the blood sugar level (hyperglycemia). The sugar content of the blood is normally about 100 mg. (70–120 mg.) per 100 cc. When the level rises to 180 mg., the renal threshold is reached, sugar appears in the urine (glycosuria), and the output of urine is greatly increased (polyuria). Symptoms include intense thirst and a marked increase in water intake. Fat metabolism is altered, for the oxidation of fats depends on the oxidation of glucose. Incomplete combustion of fats gives rise to ketone bodies and acetone makes its appearance in the urine (acetonuria). The odor of acetone may be apparent in the breath. Other ketone bodies (beta-hydroxybutyric and acetoacetic acids) are formed in excessive quantities, depleting the alkali reserve and giving rise to acidosis.

The development of generalized acidosis and the reduced capacity of the blood to carry carbon dioxide (air hunger) may bring on diabetic coma and death unless treatment intervenes. Moreover, the high blood sugar level renders diabetics particularly susceptible to infections. Wounds and injuries heal slowly, there is a tendency to develop skin ulcers, circulation is impaired (especially in the extremities), and dental and visual defects are common.

Diabetes may occur at any age, but its incidence is highest in the sixth decade. Hereditary factors seem to have a significant influence on its occurrence. Obese persons appear to be especially susceptible. Although the immediate cause of the failure of the islets to secrete insulin is not known, there is some evidence that the anterior lobe of the hypophysis and the thyroid gland may play an etiologic role. The administration of insulin does not cure the disease but merely supplies the hormone which the pancreas fails to manufacture. Since insulin utilization is determined by carbohydrate intake and utilization, dosage must be regulated on the basis of diet and activity of the individual; overdosage may produce insulin shock, convulsions, and coma; underdosage may cause diabetic symptoms. If the insulin injected has been combined with protamin and zinc, it is absorbed at a slower rate, fewer injections are needed, and the blood sugar level is kept more constant. In some cases, recently developed drugs, to be taken by mouth, are effective in reducing the blood sugar level, but, in other cases, insulin injections are still necessary. Diabetes mellitus is not a single pathological entity; there are apparently several types of diabetic disorders. The most common form of diabetes mellitus is now capable of successful oral treatment with orinase (tolbutamide). In the presence of functional beta cells of the pancreas, orinase effects the production and utilization of native insulin via normal channels.

Hyperinsulinism. Oversecretion by the islets of Langerhans causes a condition which has symptoms opposite to those of diabetes mellitus: hypoglycemia, with extreme hunger, fatigue, muscular weakness, excessive perspiration, and pallor; nervous irritability, anxiety, and neuroses; and, in extreme

cases, convulsions and coma. Immediate ingestion or intravenous injection of glucose gives temporary relief.

An overdose of insulin may induce hyperinsulinism (insulin shock). But a chronic condition may be due to tumors involving the islet tissue or to a hypersensitivity of the islets to the blood sugar level. In the latter case, a sudden rise in blood sugar increases the secretion of insulin which, in turn, reduces the blood sugar level. The administration of glucose will aggravate the condition. Treatment consists of the surgical removal of tumorous tissue or, in functional hyperinsulinism, modification of the diet, which must be high in proteins and fats (to depress insulin secretion), low in carbohydrates.

The blood sugar level is determined by a state of equilibrium between the addition of sugar to the blood and the withdrawal of sugar from the blood. The liver plays a dominant role in the homeostatic mechanisms involved. The addition of sugar occurs through absorption from the intestine or through the conversion of glycogen stores to sugar; the withdrawal occurs through oxidation of sugar or through the conversion of sugar into glycogen or fat. Normally the blood sugar level remains relatively constant throughout a variety of diets or total abstinence from food. Abnormal conditions can be detected by means of the *glucose tolerance test*, in which a quantity (100 grams) of glucose is administered after a night of fasting. In healthy subjects, the blood sugar level will rise, though rarely exceeding 150 mgs., and then slowly recede to normal. In diabetics, the blood sugar level will rise more quickly, usually exceeding 150 mgs., and tend to remain above normal; glucose may appear in the urine. In cases of hyperinsulinism, the blood sugar level may fall to a subnormal figure (70 mgs. or lower) about four hours after ingestion of glucose.

The concentration of glucose in the blood regulates the secretion of insulin by the islet cells. A sudden rise in blood sugar increases insulin production; as blood sugar falls, insulin production declines. There seems to be no nervous regulation inasmuch as pancreatic grafts devoid of nerve connections are capable of secreting insulin. Among the endocrine glands, the pancreas is in this respect unique.

Hyposecretion of Gonads; Failure of Sexual Differentiation and Maturation. Hyposecretion of the testes (hypogonadism) impedes the development of the sex organs and secondary sexual characteristics. In young patients, administration of androgenic hormones may produce favorable results; in senile individuals, the use of testosterone or the implantation of testicular tissue to restore sexual libido has not been proven to be effective.

As previously noted, estrogens produced by the ovaries are essential for the development of secondary sex characteristics and the normal functioning of the genital system. Hyposecretion of estrogens upsets the menstrual cycle, prevents the development and maintenance of sexual libido, and may result in atrophy of the uterus. Similarly, hyposecretion of progesterone may cause menstrual disorders. Progesterone is necessary during pregnancy for the normal development of the embryo; it aids in the reduction of uterine contractions and the control of bleeding. When hyposecretion threatens to result in abortion, synthetic progesterone can be administered either intramuscularly in oil or by mouth (in the latter case, large doses are required). Synthetic

estrogens are available for oral administration as therapy in ovarian disorders, in senile or menopausal inflammation of the vagina, and in nervous disturbances of the menopause. They are not so readily destroyed by the liver as the natural hormones. They must be used with caution, however, as there may be a relationship between them and the incidence of cancer in susceptible individuals.

7: THE REPRODUCTIVE SYSTEM

The reproductive system comprises those organs which are concerned with the production of new individuals of the same biologic variety, that is, with the perpetuation of the species. These organs include the primary sex organs (testes and ovaries), which produce the sex cells (spermatozoa and ova), and the accessory sex organs, including a number of structures that are concerned with bringing the sex cells together and protecting and nourishing the developing embryo.

In addition to its reproductive functions, the reproductive system exerts widespread effects on the entire life of the individual through hormones produced by the sex glands. These hormones influence bodily development and behavior—in fact, the whole psychosomatic complex of an individual.

THE PRINCIPAL REPRODUCTIVE ORGANS

The primary sex organs are the testes in the male and the ovaries in the female. In addition, there are a number of accessory sex organs.

Reproductive Organs in the Male. The principal organs of reproduction in the male are: (1) The two *testes*, which produce germ cells (spermatozoa). They are suspended from the body wall by a *spermatic cord* and enclosed in a sac, the *scrotum*. (2) A *duct system* for conveying spermatozoa to the outside. This includes the *epididymus*, two seminal *ducts* (sing., *ductus deferens*, formerly called “vas deferens”), two *ejaculatory ducts*, and *urethra*. (3) *Accessory glands* (two seminal vesicles, a prostate gland, and two bulbo-urethral glands), which contribute to the formation of seminal fluid, the vehicle for spermatozoa. (4) The *penis*, a copulatory organ, by which spermatozoa are transferred to the female.

Reproductive Organs in the Female. The principal organs of reproduction in the female are: (1) The two *ovaries*, which produce germ cells (*ova*). (2) Two *uterine tubes*, by which ova are carried from the ovaries to the uterus, and sperms are carried to the point where fertilization may take place; if this does occur, the fertilized ovum (*zygote*) is carried to the uterus. (3) The *vagina*, which serves both as a copulatory organ receiving spermatozoa from the male and as a birth canal for passage of the fetus to the outside. (4) The *uterus*, in which the fetus develops. (5) The *external genitalia*, or *vulva*, which includes the labia majora, labia minora, clitoris, and vestibule.

EMBRYONIC AND LATER DEVELOPMENT OF THE REPRODUCTIVE SYSTEM

In early embryonic development, the male and female reproductive systems follow an almost identical course, and the sexes are indistinguishable. This is known as the indifferent stage. In this stage, the gonad cannot be identified as either a testis or an ovary, and the individual possesses a double set of sex ducts. At about the sixth week of embryonic life, internal changes begin to take place which result in differentiation of the testis and ovary, and certain tubules and ducts (mesonephric tubules and ducts, Müllerian ducts) are transformed into structures which in some cases become functional, in other cases rudimentary or nonfunctional. The testes and ovaries shift their positions, too; that is, they descend and the external genitalia develop.

The following table shows some of the homologies between the male and female sexual organs:

| <i>Adult Structures in the Male</i> | <i>Indifferent Stage of the Embryo</i> | <i>Adult Structures in the Female</i> |
|---|--|--|
| Testis | Gonad on urogenital ridge | Ovary |
| Efferent ducts | Mesonephric tubules | Epoöphoron* |
| Appendix epididymis* | | Paroöphoron* |
| Paradidymis* | | |
| Ductus epididymis, ductus deferens, seminal vesicle, ejaculatory duct | Mesonephric or Wolffian duct | Gartner's duct of epoöphoron* |
| Appendix testis* | Müllerian duct | |
| Urethra, prostate gland, bulbo-urethral glands | Urogenital sinus | Uterine tubes, uterus, vagina |
| Penis | Phallus | Urethra, vestibule, para-urethral ducts, vestibular glands |
| Anal surface of penis | Lips of urogenital groove | Clitoris |
| Scrotum | Labioscrotal swellings | Labia minora |
| | | Labia majora |

* Vestigial structures

Developmental Anomalies. Occasionally, individuals are encountered in whom anatomic characteristics of both sexes are present in greater or lesser degree. When the primary sex organs of both sexes are present in the same person, the condition is *hermaphroditism*; it is a rare condition. *True* hermaphroditism, in which *functional* ovaries and testes are present, has rarely been recorded. This condition is normal in some invertebrates, such as worms and mollusks. In the development of secondary sex characteristics, such as beard, mammae, and body form, and in the development of the external genitalia, there is a wide range of variation. This sometimes leads to a condition known as *pseudo-*

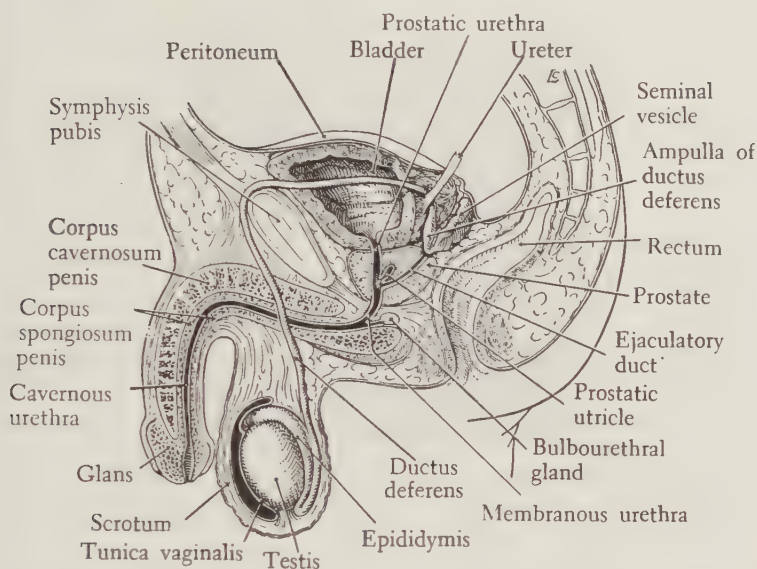
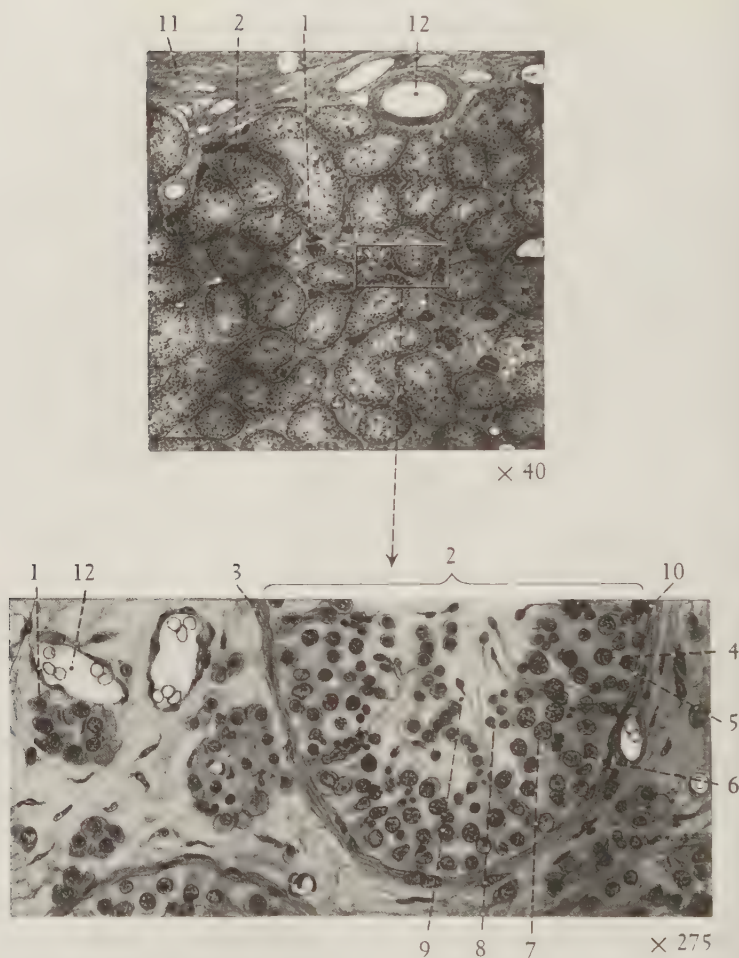


Fig. 7-1. Diagrammatic sagittal section of male pelvis. (After Turner, *General Endocrinology*.) (Reprinted with permission of W. B. Saunders Company from Millard, King, and Showers, *Human Anatomy and Physiology*, 4th ed., 1956.)

hermaphroditism, in which an individual of one sex may possess some characteristics of the opposite sex. In the male, pseudohermaphroditism may result from failure of the testes to descend (*cryptorchidism*), or from retarded development of the penis (*hypospadias*) in which the urethral opening is on the under side of the penis. Such anomalies simulate female structure. In the female, hypertrophy of the clitoris or fusion of the lips of the vulva produces a degree of resemblance to the male. Conditions in which individuals have the appropriate primary sexual organs, but secondary organs and characteristics of the other sex, are usually brought on by abnormal functioning of endocrine glands (gonads, adrenals, and hypophysis cerebri). For example, tumors of the adrenal cortex in the female (*arrhenoblastomas*) exert a masculinizing effect.

THE MALE REPRODUCTIVE SYSTEM

The Testes. These primary organs of reproduction in the male lie outside the body cavity in a sac, the *scrotum*. The testes, scrotum, and penis constitute the external genitalia of the male. Each testis is an ovoid body about 4 cm. long, 2.5 cm. wide, and 2 cm. in thickness. The outermost layer of the testis proper is the *tunica albuginea*,



- | | |
|---------------------------------|---------------------------|
| 1. Interstitial cells of Leydig | 7. Secondary spermatocyte |
| 2. Seminiferous tubule | 8. Spermatids |
| 3. Basement membrane | 9. Spermatozoa |
| 4. Primary spermatocyte | 10. Sertoli cells |
| 5. Spermatogonia | 11. Tunica albuginea |
| 6. Spermatogonia | 12. Blood vessel |

Fig. 7-2. Portion of testis, adult, showing stages of spermatogenesis. (From *Atlas of Human Anatomy*, Barnes & Noble, Inc., 1959.)

composed of dense fibrous connective tissue. Within this, the substance of the testis is divided into *lobules*, each testis containing about 250, separated from each other by partitions of connective tissue called *septulae*. Each lobule contains from one to three *seminiferous tubules*, which are minute and extremely convoluted. These tubules converge at the apex of the lobule and, joining others, form short, straight tubules, the *canaliculi recti*. These lead to a plexus, the *rete testis*, from which 15 to 20 *efferent ducts* lead to the epididymis.

FORMATION OF SPERMATOZOA. Sperms are formed in the seminiferous tubules. Each tubule is lined with epithelium consisting of two types of cells: *spermatogenic cells* and *sustentacular cells* (*cells of Sertoli*). The spermatogenic cells are of three types: *spermatogonia*, *spermatocytes*, and *spermatids*, which represent the successive stages in development up to the final form of the spermatozoon. The mature spermatozoa lie on the inner surface of the tubule with their heads

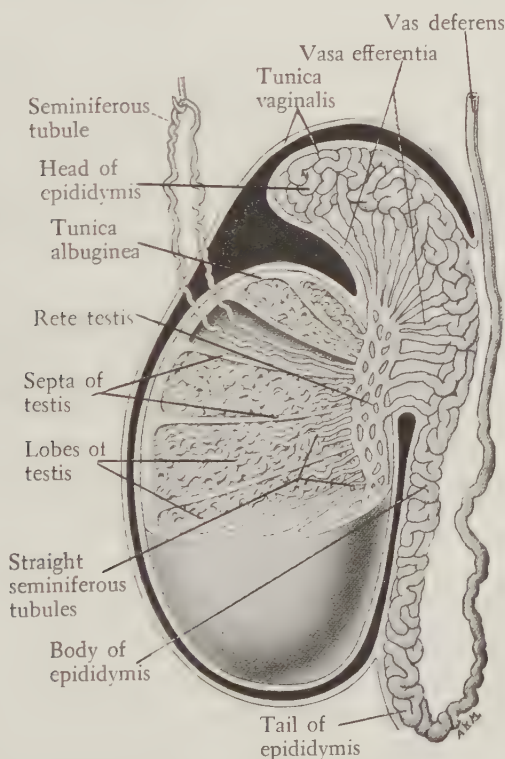


Fig. 7-3. Tubules and ducts of testis. (Reprinted with permission of St. Martin's Press and The Macmillan Company, Ltd. from Hamilton, *Textbook of Human Anatomy*, 1957.)

embedded in the cytoplasm of the cells of Sertoli, which are believed to nourish the sperms. The spermatozoa eventually are discharged into the lumen of the tubule, through which they pass to the canaliculi recti. They continue through the rete testis and the efferent ducts of the testis to the epididymis, where they are stored temporarily.

BLOOD SUPPLY OF THE TESTES. Each testis is supplied by the *internal spermatic artery*, which branches from the dorsal aorta near the kidney. The *spermatic veins* lead from the testes, the right entering the vena cava, the left entering the left renal vein. Both artery and vein pass through the inguinal canal and reach the testes by way of the *spermatic cord*.

NERVE SUPPLY OF THE TESTES. Efferent fibers from both the thoracolumbar and the sacrosacral divisions pass to the testes, the fibers ending principally in the walls of blood vessels. Whether nerve fibers enter the tubules is uncertain. Visceral afferent fibers carry sensory impulses from the testes.

EMBRYONIC DEVELOPMENT OF THE TESTES. During embryonic development the testes lie in the abdominal cavity close to the kidneys. As the fetus grows, the testes migrate downward through the ventral abdominal wall, to take their position in the scrotum. In their descent they carry with them their ducts, blood vessels, and nerves, those structures collectively forming the spermatic cord. The canal through which they pass is the *inguinal canal*, which has an internal opening, the *internal or abdominal inguinal ring*, and an external opening, the *subcutaneous inguinal ring*.

The significance of the descent of the testes to a position outside the body cavity lies in the fact that spermatozoa do not form in undescended testes. The factor primarily responsible for this is probably the higher body temperature, which exerts an inhibiting effect, causing spermatogenic cells to atrophy.

The Duct System in the Male. The system of ducts which serves the male reproductive organs includes the epididymis, the ductus deferens, the ejaculatory duct, and the urethra. All except the urethra are paired.

EPIDIDYMIS. Along the posterior and superior borders of each testis lies an elongated structure, the *epididymis*. It consists of an enlarged portion or *head*, on the superior border of the testis, and a *tail*, lying along the posterior inferior surface. Within the epididymis are 12 to 14 *efferent ducts*. These leave the rete testis as almost straight tubes, but each becomes greatly coiled before emptying into a common duct, the *ductus epididymidis*. This descends in the tail of the epididymis and becomes continuous with ductus deferens. The ductus epididymidis is a multi-coiled tube averaging 18 to 20 feet in length. It is lined with tall cells of pseudostratified columnar epithelium. On their free sur-

faces, nonmotile processes (*stereocilia*) project. These pass secretions from the cells into the lumen. A circular layer of smooth muscle fibers is present in its wall.

DUCTUS DEFERENS. This duct is a continuation of the ductus epididymidis. From the tail of epididymis it passes upward within the spermatic cord and enters the body cavity through the inguinal canal, then continues across the brim of the pelvis. It continues posteriorly alongside the lateral wall of the bladder, loops over the distal end of the ureter, then turns abruptly downward. This portion is slightly enlarged, forming an *ampulla*. At this point a lateral sacculation, the *seminal vesicle*, connects with the ductus deferens. Below the ampulla the duct narrows to form the *ejaculatory duct*.

EJACULATORY DUCT. This duct is formed by union of the ductus deferens and the duct from the seminal vesicle. It pierces the posterior surface of the prostate gland, passes downward through its substance, and enters the prostatic portion of the urethra, opening on the *colliculus seminalis*.

URETHRA. This is the common urinary and reproductive duct which leads from the bladder to the outside. It consists of three portions; the *prostatic*, *membranous* (pierces the pelvic wall), and *cavernous* (traverses the penis). Its external orifice is on the tip of the glans penis. (These portions are described in chapter 1, The Urinary System.)

The Accessory Reproductive Glands in the Male. These include the seminal vesicles, the prostate gland, and the bulbo-urethral (Cowper's) glands.

SEMINAL VESICLES. These paired structures lie against the lower posterior surface of the bladder immediately above the prostate gland. Each is a sacculated structure averaging about 5 cm. in length and 2 cm. in width. A seminal vesicle consists essentially of a tube bearing blind diverticula and folded on itself many times.

The seminal vesicles are primarily secretory in function. They produce a thick, viscid fluid which is added to the sperms coming from the testes. They may also serve to a limited extent for storage of sperm, although this function has been questioned, the presence of sperms in the seminal vesicles being regarded as accidental.

PROSTATE GLAND. This is a bilobed structure which surrounds the urethra close to its origin from the bladder. It consists of some 30 to 40 compound alveolar glands whose ducts, 16 to 32 in number, open into the prostatic portion of the urethra on each side of the *colliculus seminalis*. The glands are embedded in a stroma of connective and smooth muscle tissue.

The prostate gland secretes a thin, slightly alkaline fluid which is believed to alkalinize the urethra and to have a specific effect on the activation of spermatozoa. Frequently, *prostatic concretions* are found

in this secretion. These are spherical or ovoid bodies bearing concentric striations. They may become calcified. Prostatic concretions are also found in the gland itself, especially in cysts.

BULBO-URETHRAL (COWPER'S) GLANDS. These are two small tubulo-alveolar glands, each about the size of a pea, lying alongside the membranous portion of the urethra. Each is drained by a duct 3 to 4 cm. in length which empties into the bulb of the cavernous portion of the urethra. Their secretion is a clear, viscid, mucus-like substance which serves as a lubricant.

The Penis. The penis is a cylindrical organ composed principally of erectile tissue. It consists of a root, a body, and the glans penis. The root is that portion by which the penis is attached to the body. At the proximal end of the penis, the two *corpora cavernosa penis* diverge to form the *crura*. Each crus passes abruptly laterally and downward alongside the inferior ramus of each pubis to which it is attached. The proximal portion of the *corpus cavernosum urethrae* (*corpus spongiosum*) is enlarged to form the *bulb*, which is attached to the lower surface of the urogenital diaphragm. A *suspensory ligament* connects the sheath of the *corpora cavernosa penis* to the symphysis pubis.

The *body* of the penis consists of three cylindrical masses of erectile tissue, known as the *corpora cavernosa*. Two of these masses, the *corpora cavernosa penis*, lie alongside each other on the dorsum of the penis. The third, *corpus cavernosum urethrae*, is medially located and is traversed throughout its entire length by the urethra. The *corpora cavernosa* contain large blood spaces which, under sexual stimulation, become engorged with blood, bringing about erection of the penis. Each of these masses is enclosed by a dense fibrous membrane, the *tunica albuginea*.

The *glans penis*, the cone-shaped distal end of the penis, is a continuation of the *corpus cavernosum urethrae*. Its rounded posterior border is the *corona glandis*, behind which is a slightly narrower neck. At its tip lies the *meatus*, or urethral orifice.

INTEGUMENT OF THE PENIS. The penis is covered by integument which is continuous with that of the scrotum. This integument is loosely attached over the body of the penis, thus permitting free movement. Just behind the *corona glandis* the skin forms a fold, the *prepuce*, which extends distally, covering the *glans penis*. The extent of this covering varies. In children and in some adults, the *glans* may be completely covered (when excessive, it is called "redundant foreskin"). The *prepuce* is attached to the *glans* on its inferior surface by a median fold, the *frenum*. The skin on the *inner* surface of the *prepuce* and in the region of the neck behind the *glans penis* contains modified sebaceous glands (*glands of Tyson*). These glands secrete a substance which, together with shed epithelial cells, forms a cheese-

like waste material called *smegma*. This material collects under the prepuce.

ERECTION OF THE PENIS. The penis may undergo erection even before puberty. It occurs during sexual excitement and is normally involuntary in nature, though it can be voluntarily induced by stimulation of various structures, in particular the sex organs, or through activities of the higher nervous centers. The process is a reflex act during which vasodilation of the arteries supplying the erectile tissue occurs and the spaces in the corpora cavernosa become filled with blood. Compression of the veins reduces the outflow of blood. The resultant turgidity of the cavernous bodies causes the penis to become rigid and to assume an erect position.

Ejaculation of Seminal Fluid. Seminal fluid or semen is ejaculated during sexual intercourse (*coition*) or in states of sexual excitement. It may occur involuntarily at night during sleep (*nocturnal emission*), or it may be artificially induced (*masturbation*).

The *semen* is composed of spermatozoa and secretions from the epididymides, seminal vesicles, prostate gland, and the bulbo-urethral glands. While in the seminiferous tubules, the sperm are nonmotile; they are moved along by the flow of gradually increasing quantities of the fluid in which they are suspended. The sperm pass through the straight tubules and rete testis into the efferent ducts of the testes, where cilia propel them to the epididymis. They pass slowly through the epididymis and may even be retained there for a long time. Smooth muscles in the tubules are probably the principal factor in their passage through this region. Secretions from the tubule cells nourish the sperm, and their development is completed here.

In the ductus deferens the spermatozoa are moved rapidly by contractions of the muscles in its walls. Ejaculation is brought about by contractions of the bulbocavernous muscle and smooth muscle of the prostate gland in conjunction with the peristaltic contraction of muscles in the excretory ducts, especially the ductus deferens. An average ejaculation amounts to about 2 to 3 cc. and contains from 200,000,000 to 400,000,000 spermatozoa. The sperms in the ejaculate are very active, achieving locomotion by lashing movements of their tails. They may retain their motility for several days, but their ability to fertilize an egg is limited to approximately 24 hours.

THE FEMALE REPRODUCTIVE SYSTEM

The Ovaries. These primary organs of reproduction are paired organs lying close to the lateral walls of the pelvic cavity. Each is about the size of an almond, averaging 3 to 5 cm. in length, 2 to 3 cm. in width, and 6 to 8 gm. in weight. They are held in position by the following structures: the *mesovarium*, a mesentery which connects with

the broad ligament of the uterus; the *ovarian ligament*, which connects with the uterus; and the *suspensory ligament*, which attaches to the pelvic wall.

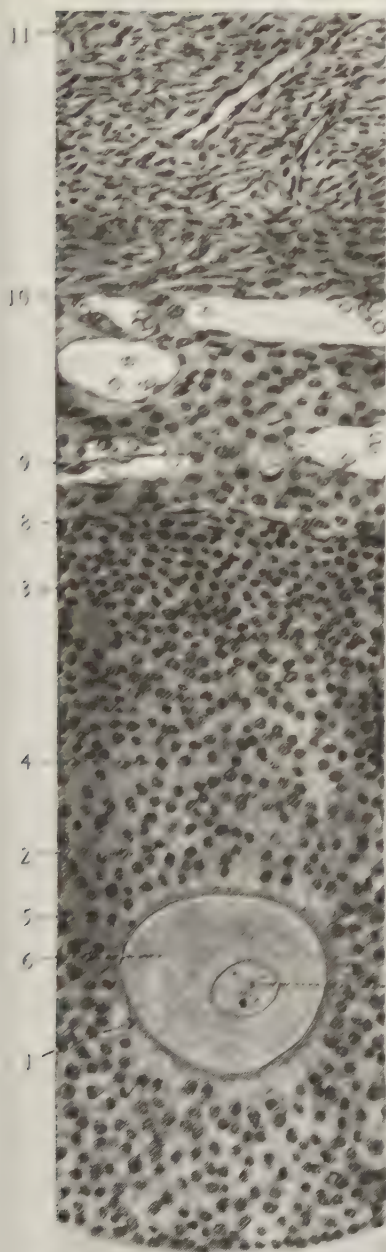
MICROSCOPIC STRUCTURE OF THE OVARIES. Each ovary has a central portion, the *medulla*, and an outer layer, the *cortex*. The medulla consists of a stroma of loose connective tissue containing blood vessels, lymphatic vessels, and some smooth muscle fibers at the region of the *hilus*, where the ovary is attached to the mesovarium. The cortex consists of a connective-tissue stroma in which are located *follicles* in various stages of development. The outermost layer of the cortex is the *germinal epithelium*, a single layer of cuboidal epithelial cells which covers the free surface of the ovary. A dense layer of connective tissue lying immediately beneath the germinal epithelium is the *tunica albuginea*. Follicles may be *primary*, *growing*, or *mature*. Corpus luteum or corpus albicans may also be present.

DEVELOPMENT OF THE OVUM AND FOLLICLE. A follicle consists of an *ovum* (or more strictly speaking, an oöcyte) surrounded by a layer or several layers of *follicle cells*. The number of follicles present is large, 400,000 or more in a single ovary in the mature female. They are present at birth; from which time they decrease in number until at menopause few, if any, remain. The decrease is brought about by an involutional process, *atresia*.

Primary Follicles. These are by far the most numerous. They lie near the periphery just beneath the tunica albuginea. Each consists of an ovum surrounded by a layer of flattened follicle cells.

Growing Follicles. As the follicle grows, the ovum increases in size, and yolk granules make their appearance. The follicle cells become cuboidal and proliferate, forming several layers around the ovum, from which they now become separated by a clear membrane, the *zona pellucida*. As development proceeds, the follicle increases in size and irregular spaces filled with follicular fluid appear between the follicle cells. Later, these spaces coalesce and form a single cavity, the *antrum*. The follicle is now *mature* and is known as a *vesicular* or *Graafian follicle*. The ovum occupies a position at the periphery where it is attached to the wall of the follicle by a mass of cells, the *cumulus oöphorus*. The connective tissue surrounding the follicle becomes differentiated into a capsule, the *theca folliculi*, which forms the outer wall of the follicle. This is separated from the inner layer of follicle cells, the *stratum granulosum*, by a basement membrane.

Mature Graafian Follicle. The cavity within the follicle increases in size, eventually occupying the entire thickness of the cortex, even protruding from the surface. The human follicle reaches a diameter of 12 to 15 mm. when fully developed and occupies at least one-fourth of the whole volume of the ovary. The ovum also increases in size,



1. Ovum (oocyte)
2. Corona radiata (epithelial follicular cells)
3. Cumulus oophorus
4. Mitosis in follicular cell
5. Zona pellucida
6. Cytoplasm of ovum
7. Nucleus with nucleolus
8. Basement membrane
9. Theca interna with abundant blood vessels
10. Theca externa with fewer blood vessels
11. Ovarian stroma

Fig. 7.4. Diagram of ovary. (From Atlas of Human Anatomy, Barnes & Noble, Inc., 1959.)

attaining a diameter of about .2 mm. It has a large vesicular nucleus with a conspicuous nucleolus. The tall columnar follicle cells around the ovum become arranged in a radial fashion and form the *corona radiata* (*discus proligerus*). The ovum is attached to the follicle wall by only a narrow strand of follicle cells.

At this point the follicle may either (1) undergo involution or retrogression or (2) rupture, liberating its contained ovum. The latter process is *ovulation*.

HORMONAL CONTROL OF OVARIAN ACTIVITY. The development of the follicle and the corpus luteum is under the control of gonadotrophic hormones of the anterior pituitary. These are (1) *follicle-stimulating hormone* (FSH) which stimulates the development of immature follicles into mature (Graafian) follicles, (2) *luteinizing hormone* (LH) which induces ovulation and development of the corpus luteum, and (3) *luteotrophic hormone* (LTH) which maintains corpus luteum and induces secretion of progesterone.

Ovulation is the discharge of the ovum from the Graafian follicle. At the point where the follicle bulges from the ovary wall, the stroma becomes very thin and vascular. This region is called the *stigma*, and it is here that the follicular wall undergoes lysis (loosening or thinning out) and the ovum, with its corona radiata and together with the follicular fluid, slowly flows from the follicle out into the peritoneal cavity. This emergence is often incorrectly conceived as an "eruption" or "bursting" through the ovarian wall. But neither these terms nor "rupture" provides the best description of the process, which actually is rather a gentle one.

In the human female, ovulation occurs on an average once each 28 days from the time of puberty to the menopause. During periods of pregnancy no follicles are developed, and ovulation ceases. Ovulation may occur alternately in each ovary, or a single ovary may liberate ova several times in succession. Usually, a single ovum is discharged, but two or more from different follicles may be liberated. Usually, too, a follicle contains a single ovum, but it may hold two or more. In a lifetime about 400 ova are developed and liberated by the average female.

Involution or *atresia* is the process in which follicles degenerate and disappear. Of the 400,000 follicles present in the ovaries of a female at birth, only about 400 mature and discharge their ova; the remainder undergo atresia. This may begin at any stage in the development of a follicle, and it may occur at any stage of life of the woman. Ordinarily, though, it begins during intrauterine development and is most active between the years of birth and puberty. It continues during active sexual life until menopause, at which time follicles cease to develop, though occasionally a few may persist until old age.

EVENTS FOLLOWING OVULATION. After ovulation has occurred, the ovum enters the fimbriated end of the uterine tube. If coition has taken place, sperms are usually present in the tube, and fertilization occurs. The fertilized ovum or *zygote* now begins development, which continues as it passes through the uterine tube into the uterus. Here *nidation* (*implantation*) in the uterine mucosa takes place at about the 8th or 9th day. If no sperms are present, the ovum is not fertilized and fails to develop. It disintegrates in its passage through the uterine tube.

DEVELOPMENT OF THE CORPUS LUTEUM. Upon discharge of the ovum and the liquor folliculi at ovulation, the wall of the follicle collapses and its inner layer, the stratum granulosum, becomes folded. The rupture of capillaries causes a small amount of blood to accumulate in the follicular cavity, forming the *corpus hemorrhagicum*. Cells from the stratum granulosum enlarge, and the number of cell layers increases. *Lutein*, a yellowish substance which is lipoidal in nature, fills the cytoplasm of these cells. These *lutein cells* form a mass, the *corpus luteum*, which fills the follicular cavity and reaches the peak of its development about 12 days after ovulation.

If the ovum is not fertilized, this body is known as the *corpus luteum of menstruation* (*corpus luteum spurium*), which, after a period of about 14 days, begins to degenerate. The lutein cells decrease in size and are replaced by connective tissue. After a period of a few weeks, a small white body (the *corpus albicans*) is all that remains where once the follicle was located; this body may persist for months.

If the ovum is fertilized, the corpus luteum does not degenerate, but persists as the *true corpus luteum*. About the third month of pregnancy degenerative changes begin which proceed throughout the remainder of pregnancy, and the corpus luteum slowly retrogresses.

BLOOD AND NERVE SUPPLY OF THE OVARIES. The ovary receives blood through the ovarian artery and a branch of the uterine artery. Veins emerge from the hilus as tortuous vessels which unite with those from the uterus, to form a venous complex, the *pampiniform plexus*. From this plexus, blood leaves by the ovarian or the uterine veins. The right ovarian vein empties into the vena cava, the left into the left renal vein; the uterine vein empties into the internal iliac vein.

Efferent lymphatic vessels convey lymph to the lumbar lymph nodes.

Nerves from both divisions of the autonomic nervous system innervate the ovaries.

The Uterine Tubes (Fallopian Tubes, Oviducts). These two tubes convey the ova that are discharged by the ovary to the uterus. Each tube lies in the upper portion of the broad ligament and averages about 12 cm. in length and 1 cm. in diameter. The proximal end of each tube opens into the uterus, the distal into the pelvic portion of the peritoneal cavity by an opening, the *ostium*. The wide, expanded por-

tion that surrounds the ostium is the *infundibulum*. Its border has a fringed appearance, bearing many processes called *fimbriae*; one of these, the *fimbria ovarica*, is much longer than the others, reaching nearly to the ovary. The infundibulum lies close to and may partially enclose the ovary, but there is no direct connection between the two; a small peritoneal space always intervenes. The portion of the tube into which the infundibulum opens is the *ampulla*. Near the uterus the tube becomes straight and narrow, to form the *isthmus*.

MICROSCOPIC STRUCTURE OF THE UTERINE TUBES. The wall of a uterine tube consists of three layers: mucosa, muscular coat, and serosa. The *mucosa*, or innermost layer, consists of columnar epithelial cells resting on a thin lamina propria of connective tissue. Some of the epithelial cells are ciliated; others are glandular. The cilia beat toward the uterus. The mucosa is thrown into numerous folds, which bear secondary and tertiary folds. The folds are very numerous in the ampulla, but in the isthmus they are few in number. The *muscular layer* consists of an inner circular and an outer longitudinal layer. These are not clearly separated from each other, for some fibers of the circular layers are directed in a spiral fashion. In the region of the fimbria, the longitudinal layer is lacking. The *serosa* or outer coat consists of connective tissue underlying the outermost layer of *peritoneum*. The connective tissue is continuous with that of the *broad ligament*.

FUNCTION OF THE UTERINE TUBES. After the ovum has left the ovary, it enters the fimbriated end of the uterine tube. At the time of ovulation, vascular changes in the fimbriae cause them to become enlarged and turgid. This, together with contraction of muscular fibers, brings the ostium in close proximity to the ovary. When the ovum is discharged, currents produced by the action of cilia cause the ovum to be drawn into the oviduct. Further transport of the ovum is accomplished primarily by the peristaltic muscular contractions of the oviduct.

Fertilization usually occurs in the fimbriated end of the oviduct, after sperm have entered the tube from the uterus. They make their way distally by means of their own flagellated movements against ciliary action. But fertilization may occur outside the tube, resulting in a relatively uncommon (but not rare) development known as *ectopic* or *extrauterine pregnancy*. After fertilization, the zygote, while passing through the uterine tube, undergoes segmentation. On arriving at the uterus eight or nine days later, it has reached the stage in development in which it is known as a *chorionic vesicle*. If passage of the blastocyst through the tube is arrested, as may occur when inflammatory conditions exist within the tube, implantation may take place within the tube, resulting in *tubal pregnancy*. (As the embryo develops, the tube expands, but eventually it ruptures, usually with serious effects from the ensuing hemorrhage.)

The Uterus. This is a muscular pear-shaped organ lying in the pelvic cavity between the bladder and the rectum. It averages 6.0 cm. in length, 4.5 cm. in width, and 2.5 cm. in thickness. It is slightly flattened anteroposteriorly. During pregnancy it increases considerably in size.

REGIONS OF THE UTERUS. The uterus consists of three regions: body, isthmus, and cervix. The *body* forms the expanded upper portion; the *cervix*, the narrower lower portion. These are separated by a slight constriction, the *isthmus*. The superior portion of the body, which lies above the openings of the two uterine tubes, is the *fundus*. The portion of the cervix that protrudes into the vagina is the *portio vaginalis*.

POSITION AND ATTACHMENT OF THE UTERUS. The cavity of the uterus is roughly triangular in shape, and it is relatively small owing to the thickness of the uterine wall. Laterally, it receives the two uterine tubes; inferiorly, it narrows and continues through the cervix as the *cervical canal*, which opens into the vagina. The vaginal opening is called the *external os*; the internal or uterine opening is the *internal os*. On the anterior and posterior inner surfaces of the cervical canal are two longitudinal folds, the *plicae palmae*.

In an erect female with the bladder empty, the uterus lies nearly horizontal, with the fundus directed forward. Its anterior surface is separated from the bladder by a space lined with peritoneum, the *vesicouterine pouch*. Posterior to the uterus and separating it from the rectum is a space, the *recto-uterine pouch* or *pouch of Douglas*. This pouch is the lowermost portion of the peritoneal cavity. It extends inferiorly as far as the vagina.

The uterus is held in position by (1) two *broad ligaments*, wing-like structures extending horizontally which attach to the floor and wall of the pelvis; (2) two *round ligaments* (sing., *ligamentum teres uteri*), which extend from the upper portion of the uterus near the openings of the uterine tubes laterally to the pelvic wall (these continue through the inguinal canal and end in the subcutaneous tissue of the labium majus); and (3) two *uterosacral ligaments*, which extend from the upper portion of the cervix to the sacrum. The lower portion of the uterus is relatively fixed in position; the body is relatively free and movable.

MICROSCOPIC STRUCTURE OF THE UTERUS. The wall of the uterus is quite thick, especially in the region of the fundus, where it measures 1 to 1.5 cm. in thickness. It consists of three layers: the mucosa (endometrium), muscular layer (myometrium), and serosa (perimetrium). The *mucosa* consists of a single layer of simple columnar epithelium resting on a connective tissue stroma that has the nature of mesenchyme. Irregularly distributed over its surface are groups of ciliated cells. The uterine glands are invaginations of the epithelium. They

THE REPRODUCTIVE SYSTEM

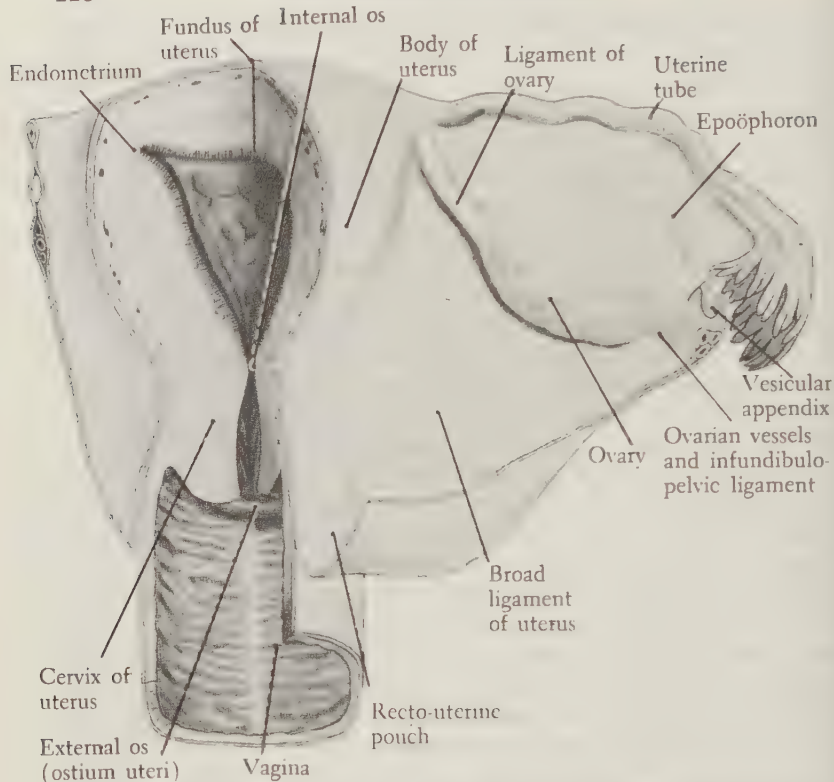


Fig. 7-5. Posterior view of uterus, upper part of vagina, and broad ligament. Left half of posterior wall of uterus removed. (Reprinted with permission of St. Martin's Press and The Macmillan Company, Ltd. from Hamilton, *Textbook of Human Anatomy*, 1957.)

are usually of the simple tubular type, although some are branched. The tubular portion of a uterine gland follows a tortuous course through the stroma, and the terminal portion may extend into the myometrium (muscle layer). Some of the cells of these glands bear cilia. The *muscular layer* constitutes the major portion of the uterine wall. It consists of bundles of smooth muscle cells arranged in three indistinct layers (inner longitudinal, middle circular, and outer longitudinal). The muscle cells are long, averaging 50 microns or more in length. In a pregnant uterus, however, they hypertrophy, sometimes attaining a length of 500 microns or more. There is also an increase in the *number* of muscle cells as a result of cell division and transformation of other cellular elements into muscle cells. The bundles of muscle cells are bound together by interstitial tissue consisting principally of collagenous fibers, but containing embryonic connective

tissue cells and other cellular elements. Elastic fibers are abundant, especially between the serosa and the muscular layer. The *serosa*, the outermost layer, consists of fibro-elastic tissue. On the entire posterior surface and the upper portion of the anterior surface, a layer of mesothelium continuous with the abdominal peritoneum forms the outer surface.

CYCLIC CHANGES IN THE ENDOMETRIUM—MENSTRUATION. In non-pregnant women from the time of puberty (ages 12 to 14) to menopause (ages 45 to 55), the endometrium of the uterus undergoes a series of cyclic changes, which occurs on the average every 28 days (may vary from 21 to 35 days). These cyclic changes of the endometrium, known as the *menstrual cycle*, are correlated with cyclic changes in the ovaries, already described.

Stages of the Menstrual Cycle. Menstruation is the periodic discharge from the vagina of blood that contains necrotic tissue elements which have been sloughed off from the uterine endometrium. The following table lists the periods of the menstrual cycle and the changes that occur in the uterine mucosa and in the ovaries:

| <i>Period</i> | <i>Duration in Days</i> | <i>Day of Cycle</i> | <i>Changes in Uterine Mucosa</i> | <i>Changes in Ovaries</i> |
|---|-----------------------------|-------------------------|--|---|
| Menstruation | 5 | 1st to 5 | Endometrial cells undergo necrosis; desquamation occurs; glands release secretions, blood vessels rupture, menstrual flow occurs | Corpus luteum continues to degenerate New follicle begins development |
| Repair and regeneration | 2 | 5th to 7th | Uterine mucosa is restored | Follicle develops |
| Proliferative phase | 8 | 7th to 15th | Endometrium grows, stroma becomes thicker, more vascular; glands longer, but remain straight | Follicle matures and develops Estrogens are secreted Ovulation marks end of stage |
| Premenstrual, secretory, progestational or pro-gravid phase | 13 | 16th to 28th | Endometrium continues to grow; glands become longer, more tortuous and coiled. Cells enter secretory phase, secrete glycogen, mucoid material, and fat | Corpus luteum develops, matures, and begins to retrogress Secretes progesterone |

(In long cycles of 30 to 35 days, a period of rest intervenes between the first and second stages shown in the table.)

Actually, menstruation is the final event of the cycle, but it is customary to speak of the "menstrual cycle" as beginning with the onset of menstruation; that is, the first day that menstrual discharge appears is considered to be the first day of the cycle.

Uterine Changes during the Menstrual Cycle. As shown in the preceding table, the uterine changes that take place during the menstrual cycle are correlated with changes that are occurring in the ovary. In fact, they are brought about and regulated by the effects of certain hormones produced in the endocrine tissue of the ovaries: follicular or estrogenic hormones and the corpus luteum hormone (progesterone).

The follicular or estrogenic hormones, of which estradiol is the principal one, are produced by the cells of the developing follicle. They exert their effects during the first half of the menstrual cycle. Under their influence, repair of the endometrium shed during menstruation takes place. The mucosa becomes thicker, glands develop and begin secreting, and the blood supply increases. These changes prepare the uterus for reception of the fertilized egg. Upon ovulation, secretion of the follicular hormones is reduced, but ovarian control is continued through the action of progesterone.

The corpus luteum hormone, called *progesterone*, is produced by the corpus luteum, a structure which develops within the ruptured follicle. It is responsible for changes that occur in the uterine mucosa during the second half of the menstrual cycle (premenstrual changes). These changes vary, depending on whether or not the ovum is fertilized. If the ovum is *not* fertilized, the mucosa becomes thicker, glands increase in size and become tortuous, cells become filled with glycogen, and the blood supply increases. As the corpus luteum retrogresses, the reduction in the amount of progesterone secreted presumably induces menstruation. If the ovum is fertilized, the foregoing changes are modified as follows: the mucosa is in a state ready to receive the fertilized ovum; consequently, when the developing blastocyst enters the uterus, it embeds itself (*implantation*) and continues its development. Under this condition, the corpus luteum does not involute but persists as the corpus luteum of pregnancy (*true corpus luteum*). Menstruation does not take place, and further ovulation is inhibited. Progesterone further influences the endometrium, and its continued secretion is necessary for the proper development of the embryonic membranes and the placenta.

Irregularities in the Menstrual Cycle. Though tending to occur with regularity, the menstrual cycle is subject to considerable variation. Factors which affect physical and mental health may also affect the onset of the menstrual flow. In wasting diseases, the menstrual periods are usually suppressed. Emotional disturbances may bring about delay

in menstruation. Except during pregnancy, the absence of menstrual flow is regarded as abnormal; the condition is termed *amenorrhea*. Scanty menstrual flow is called *oligomenorrhea*; painful menstruation, *dysmenorrhea*; excessive flow, *menorrhagia*. Menstrual disorders may result from diseases involving the uterus or ovaries, abnormal growths (cysts, tumors), endocrine dysfunction, or psychogenic disturbances.

Anovulatory Menstruation. Menstruation may occur in the absence of ovulation, that is, before the endometrium has entered the secretory period. Such cycles, which are usually shorter than ordinary cycles, are sterile, for no ovum is produced. They occur most commonly during the years immediately following the onset of puberty and in those just preceding the menopause. It is the anovulatory nature of these cycles that accounts for the relative infertility of women during those periods of life.

"FERTILE" AND "SAFE" PERIODS. Most experimental evidence indicates that ovulation occurs between the 14th and 16th days of the menstrual cycle; as a consequence, fertilization or "conception" takes place most frequently about midway between menstrual periods. This is the so-called "fertile period." After ovulation, the ovum is thought to maintain its viability for a limited period (not exceeding one or two days). From this it can be concluded that fertilization is unlikely to occur during the week prior to menstruation. The advent of menstruation indicates that the ovum has not become fertilized, and in the period following menstruation, when the new follicle is being developed, fertilization cannot occur because an ovum has not been liberated from the follicle. Thus, the week preceding and the week following menstruation may be considered as relatively "safe" periods; that is, periods in which fertilization is not likely to occur.

MENOPAUSE. This is the period marked by the permanent cessation of menstruation. It may take place at any time between the ages of 35 and 55 but is most common between 45 and 50. Development of ovarian follicles ceases; consequently, the menopause marks the end of the child-bearing period. But normal libido usually persists.

Certain *anatomic* changes accompany the menopause, among them atrophy of the sex organs, including the external genitalia, uterus, uterine tubes, ovaries, and breasts. The vagina becomes conical in shape, and its mucous membrane atrophies. Secretory activity of glands associated with the reproductive organs is reduced. Most of these changes are gradual and extend over a period of years. Pronounced *physiologic* changes may occur. Among these are: "hot flushes," sweating, dizziness, rheumatic pains in joints, susceptibility to fatigue, and headaches. There may also be *psychic* changes: excessive irritability, abnormal fears, and a tendency to worry. Sometimes, excessive sexual desire is manifested. Many of these symptoms can be

alleviated by the administration of pituitary and sex hormones; during the menopause, there is marked hormonal imbalance.

The menopause can be induced prematurely (*artificial menopause*) by removal or deactivation of ovarian tissue. This is accomplished either surgically or by irradiation.

The Vagina. The vagina is the canal which extends from the uterus to its external opening in the *vestibule*. It is a highly muscular, dilatable tube, averaging 7.5 cm. in length. Its upper end meets the cervix of the uterus at almost a right angle so that its posterior wall is longer than the anterior wall. Because the cervix projects downward into the vagina, a circular groove encircles the lowermost portion of the cervix. This groove is called the *fornix*. Its *posterior portion* (*posterior fornix*) is deeper than the *anterior fornix*.

THE HYMEN. The external orifice of the vagina lies between the minor labia and is partially closed by a fold of connective tissue, the *hymen*, which is usually ruptured at the first coition, though this often is caused in other ways. When the hymen completely closes the vaginal orifice, it is said to be an *imperforate hymen*.

LAYERS OF THE VAGINAL WALL. The wall of the vagina consists of three layers: mucosa, muscular layer, and fibrous coat.

Mucosa. This is lined with stratified squamous epithelial cells resting on a thin lamina propria of connective tissue. The lamina propria sends numerous extensions or papillae into the overlying epithelium especially on the posterior wall of the vagina. It also contains numerous lymphocytes which migrate into the epithelium. Sometimes, the lymphocytes are grouped into small nodules.

The mucosa is thrown into large folds or *rugae*, in which blood vessels abound, giving it the structure of erectile tissue. Glands are absent, but the vagina is moistened by mucous secretions of the uterine glands. The pH of the vagina is slightly acid owing to the action of lactic-acid-forming bacteria (*Döderlein's bacilli*), which ferment the glycogen. The pH varies with the phases of the menstrual cycle, being lowest in the late, proliferative phase.

Muscular Coat. This consists of bundles of smooth muscle, the majority of which are directed longitudinally. Circular bundles are interspersed among the longitudinal ones. As the external orifice a sphincter muscle of striated fibers is present.

Fibrous Coat. This is a thin layer of connective tissue which merges with the loose tissue of surrounding structures. Posterior to the vagina is a sheet of fibroclastic tissue, the *retrovaginal septum*, which separates the vagina from the rectum. Anteriorly, the *urethrovaginal septum* separates the vagina from the urethra.

CHANGES IN THE VAGINA DURING PREGNANCY. During pregnancy certain changes occur in the structure of the vagina which are corre-

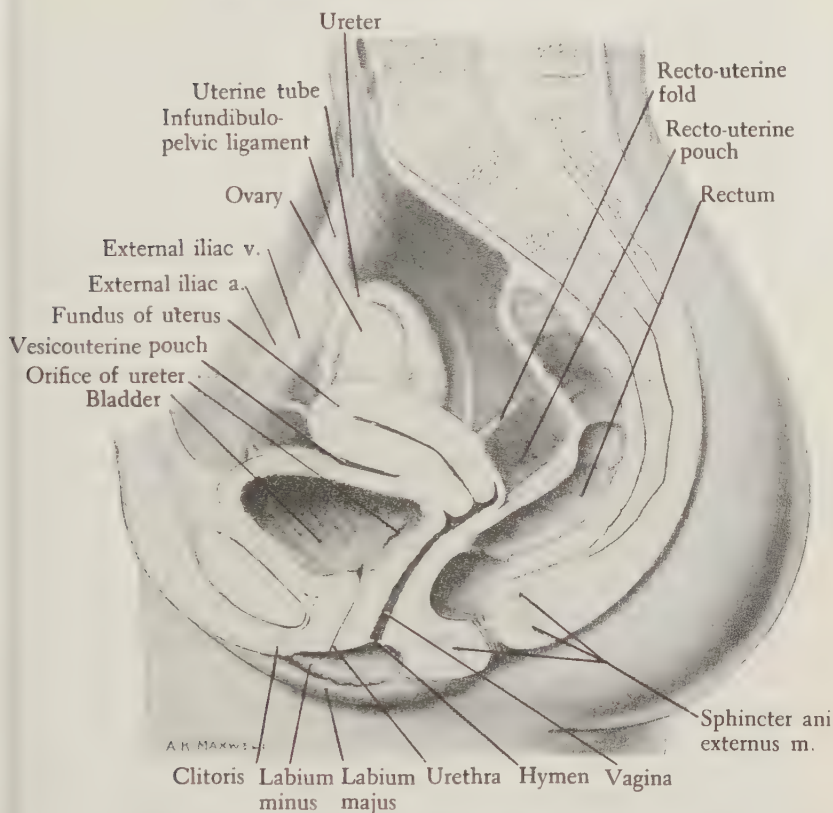


Fig. 7-6. A median sagittal section through the female pelvis. (Reprinted with permission of St. Martin's Press and The Macmillan Company, Ltd. from Hamilton, *Textbook of Human Anatomy*, 1957.)

lated with its role in childbirth. The epithelium proliferates, muscle cells hypertrophy, and the connective tissue becomes more loosely arranged. This enables the vagina to stretch, thus accommodating the fetus. Prolonged and difficult labor may result in development of lesions, as, for example, laceration or fistulas. (A *fistula* is an abnormal passageway between two cavities or from a cavity to the outside.) Fistulas may develop from the vagina to the bladder, urethra, or rectum. In cases in which laceration of the perineum is imminent, it is common practice to make an incision on one side through the vulva, in order to direct the tear to the side (a procedure called *episiotomy*).

The External Genitalia. The external female sexual organs include the labia majora, labia minora, clitoris, and vestibule. Collectively they are called the *vulva*.

The *labia majora* are two prominent folds of skin bearing pubic hair, which form the lateral borders of the vulva. They unite anteriorly and are continuous with the *mons veneris* (*mons pubis*), a rounded prominence which covers the pubic symphysis. The mons pubis has a dense pad of fat lying beneath the integument and is thickly covered with pubic hair. Posteriorly, the labia majora unite to form the *posterior commissure*.

The *labia minora* are two longitudinal folds which lie just within the labia majora. They form the lateral borders of the vestibule. Anteriorly, they unite to form the *prepuce* and the *frenulum clitoridis*.

The *clitoris* is a small erectile structure lying beneath the pubic symphysis at the juncture of the labia minora. It consists of a *body*, two *crura*, and a *glans*, and is covered by the prepuce. It contains many sensory nerve endings. The clitoris is a homolog of the penis in the male.

The *vestibule* is the region between the labia minora into which the vagina and the urethra open. On each side of the vaginal orifice and just within the labia minora are the openings of the larger *vestibular glands* (*glands of Bartholin*). Smaller vestibular glands open at various points in the vestibule.

The muscles and fascia which form the pelvic floor and enclose the reproductive, urinary, and digestive openings constitute the *perineum*. In obstetrics the term perineum is restricted to that region which lies between the vulva and the anus (*obstetrical perineum*).

The Mammary Glands. In the strictest anatomic sense, the mammary glands belong to the integumentary system, since structurally they are modified sweat glands. Their development and functioning are, however, closely related to those of the reproductive system. Mammary glands are present in both sexes, but involution occurs in the male after puberty and they persist in only a rudimentary state. They undergo conspicuous changes in the female at puberty, during pregnancy, during and after lactation, and after menopause.

STRUCTURE OF THE MAMMARY GLANDS. The mammary glands are contained in the breasts or *mammæ*, two rounded bodies which lie on the anterior surface of the thorax. The secreting portion is surrounded by a considerable amount of loose connective tissue in which are contained variable quantities of adipose tissue. The *nipple*, a cylindrical or conical projection at about the center of each mamma, bears a rounded tip on which open some 15 to 20 *lactiferous ducts*. Surrounding each nipple is a circular pigmented area, the *areola*. The skin over the nipple and areola bears numerous small papillae and contains a considerable amount of pigment, which becomes much darker during pregnancy. During pregnancy the nipple increases in size, becomes more sensitive, and is more easily erectile. Smooth muscle fibers are present in the

skin beneath the areola and the nipple. About the base of the nipple they are disposed in a circular fashion. Also present in the skin of the areola are small *areolar glands of Montgomery* (*rudimentary milk glands*) and sebaceous glands in large numbers, which produce slight elevations.

Each mammary gland is a compound alveolar gland consisting of 15 to 20 lobes of glandular tissue separated from each other by *interlobular septa*. In an inactive gland the alveoli or secreting elements are small and undeveloped. In fact, their presence has been questioned by those who maintain that only ducts and their branches persist.

When pregnancy occurs, the mammary glands become active and undergo marked changes. After lactation they undergo involution, in which the secreting portions become greatly reduced in size, or disappear. After menopause they become still further reduced in size, and in old age appear as mere fibrous cords. The interstitial tissue also retrogresses, giving the entire structure a shrunken appearance.

HORMONES AND THE MAMMARY GLANDS. The growth and development of the mammary glands and the secretion of milk by them are regulated by endocrine secretions of the ovaries and the hypophysis cerebri. Estrogens produced by the follicle cells of the ovary and by the placenta induce early growth and development of the duct system. *Progesterone*, produced by the corpus luteum of the ovary and the placenta, brings about development of the alveoli and induces presecretory changes. *Prolactin*, from the anterior lobe of the pituitary gland (hypophysis cerebri), brings about the active secretion of milk.

BLOOD, LYMPH, AND NERVE SUPPLY OF THE MAMMARY GLANDS. The mammary glands receive their principal blood supply from branches of the internal mammary artery supplemented by branches from the axillary and the intercostal arteries. Veins empty into the axillary and internal mammary veins. Lymphatic vessels are numerous; the efferent vessels drain by two principal trunks leading to the axillary nodes. Supplementary drainage leads through the pectoralis major muscle to the mediastinal nodes or the abdominal lymph nodes. The nerve supply to the glands is abundant. Branches from the intercostal nerves and from the supraclavicular nerve innervate the glands and the overlying skin. Branches of the autonomic nervous system innervate muscles of the blood vessels of the nipple, areola, and glandular tissues. The nipple is well supplied with afferent endings.

DISEASES AND DISORDERS OF THE REPRODUCTIVE SYSTEM

The Male

Anorchidism. Congenital absence of testes.

Cryptorchism. Failure of testes to descend into scrotum during embryonic development. It results in sterility; sperms fail to develop when the testes, in-

stead of migrating downward through the ventral abdominal wall, are retained in the body cavity.

Hydrocele. Accumulation of fluid in tunica vaginalis or testis.

Monorchidism. Presence of only one testis.

Phimosis. Inability to retract the prepuce over the glans penis. It may be due to adhesions of the prepuce to the glans or to a narrowing of the preputial orifice. The condition is corrected by circumcision.

Prostatic Hypertrophy. Enlargement of prostate gland. It occurs frequently in men after the age of sixty. When enlarged, the prostate compresses the prostatic portion of the urethra, leading to difficulty in or complete suppression of urination.

Urethral Stricture. Localized constriction of urethra. It may be due to a spasm of the urethral muscle, inflammation of the urethral lining, or formation of fibrous tissue.

Vesiculitis. Inflammation of a seminal vesicle.

The Female

Anteversion (Retroversion) of Uterus. Forward (backward) tilt or displacement of the fundus toward (or away from) the pubis.

Cysts. These are common within or upon the ovary. Among them are *dermoid* cysts, which contain ectodermal derivatives, such as skin, hair, and teeth.

Prolapsed Uterus. This is the condition that prevails when the normal supporting structures weaken and permit the uterus to drop from its usual position.

Tumors. The uterus, ovaries, and breasts are especially prone to development of neoplasms (new growths). While most of these are benign, some are malignant.

Vaginismus. Spasm of the muscles of the walls of the vagina, which prevents coition. The cause may be either somatic or psychic in nature.

Vaginitis. Inflammation of the vagina, usually due to infectious organisms.

Both Sexes

Sterility. Inability to produce offspring. In the *male*, this may be due to (1) failure of the testes to produce sperms, or production of sperms that lack fertilizing power; (2) *impotency*, or inability to perform the sexual act; (3) obstruction of the seminal ducts. In the *female*, it may be due to (1) deleterious effects of vaginal secretions on sperms; (2) endocrine dysfunction, especially of the ovary and the hypophysis cerebri; (3) obstructions in the genital passageways (for example, a mucous plug at the cervix may prevent entrance of a sperm, or a cyst or inflammation in an oviduct may prevent passage of either sperm or ovum).

Venereal Diseases. These infectious diseases, usually acquired through sexual relations with an infected person, include chaneroid, gonorrhea, and syphilis. *Chaneroid* results in the formation of multiple soft lesions (chaneres); the infecting agent is a bacterium, *Hemophilus ducreyi*. The lymph nodes are usually involved. *Gonorrhea* is an infectious inflammatory condition involving the mucous membranes of the reproductive organs. It is caused by a gonococcus, *Neisseria gonorrhoeae*. *Syphilis*, usually chronic in nature, is caused by a spiro-

chete, *Treponema pallidum*. Symptoms of syphilis appear in three stages. In the *primary stage*, the initial lesion appears two to four weeks after infection; it develops into a hard chancre. In the *secondary stage*, constitutional symptoms appear 6 to 18 weeks after the exposure to infection, and may involve almost any organ of the body, though skin manifestations are common. The symptoms of this stage are often mistaken for those of other diseases, a fact which has caused syphilis to be called "the great imitator." In the *tertiary stage*, there is degeneration of structures such as bone, walls of blood vessels, or the brain; indeed, any organ may be involved. The symptoms of this stage do not develop before six months, in some cases not for years. When the central nervous system is affected, the condition is known as *general paresis*.

8: REPRODUCTION AND DEVELOPMENT

Reproduction and development include all processes concerned with the production of a new individual: the formation of germ cells (spermatozoa and ova), transfer of sperm to the female (copulation or coition), fertilization of the ovum, segmentation and implantation of the zygote, development of the embryo, formation of embryonic membranes and placenta, parturition (childbirth), and lactation.

CELLULAR BASIS OF HUMAN REPRODUCTION

Individuals begin development as a single cell, a fertilized ovum or *zygote*. By the process of mitosis, this cell divides into two cells, these two into four, the four into eight, and so on until a complex individual consisting of billions of cells results. At first all the cells are nearly identical, but, as development proceeds, *differentiation* and *specialization* take place, giving rise to the formation of *tissues*. These tissues eventually become associated, forming *organs*, and the organs become grouped together in *body systems*.

Fundamental Cell Types. In the mature organism, cells of the body fall into one or the other of two types: (1) *germ* or *reproductive cells*, which have the capacity to produce a new individual; and (2) *somatic* or *body cells*, which constitute the major portion of the body.

Development and Maturation of Germ Cells. The development of female germ cells (ova) is known as oögenesis; of the male germ cells (spermatozoa), spermatogenesis.

OÖGENESIS. There are two views concerning the origin of functional human ova: (1) that they are developed within follicles, which arise from the germinal epithelium of the ovary very early in the development of that organ—and that most of the ova are present before birth and lie dormant until maturity, when a limited number mature and become functional; (2) that functional ova arise from indifferent cells of the germinal epithelium as they are needed in the adult female.

In the process of maturation, the ovum is prepared for fertilization. It increases in size through accumulation of food materials, and nuclear changes occur in which the chromosome number is reduced to one-half the normal number.

In oögenesis there are four stages, as follows:

1. *Oögonia*. These are generalized cells which develop from the primordial germ cells in the germinal epithelium. They become en-

closed in a single layer of follicle cells. From these the follicle develops, and the germ cell enlarges to become a primary oöcyte.

2. *Primary oöcyte*. The follicle matures, and a day or two before ovulation the primary oöcyte undergoes division. In this division, the chromosomes come together in pairs (*synapsis*) and each synaptic pair divides, one chromosome of each pair going intact to each of the daughter cells. This results in two daughter cells, each with one-half the normal chromosome content. The daughter cells vary greatly in size. One is very large, retaining practically all the cytoplasm of the parent cell; it is called a *secondary oöcyte*. The other, which is very small and contains little cytoplasm, is the *first polar body*.

In this division of the primary oöcyte, the normal somatic number of chromosomes has been reduced from 46 to 23; accordingly, it is known as the *reduction division*.

3. *Secondary oöcyte*. In this stage the oöcyte is usually liberated from the follicle (ovulation). It is drawn into the uterine tube where, if sperms are present, fertilization will probably occur. The entry of sperm into the oöcyte initiates this second division, in the course of which the secondary oöcyte divides into a very large cell (the *functional ovum*) and the *second polar body*. Sometimes the first polar body also divides, in which case there may be three polar bodies from one oögonium.

4. *Mature ovum*. In this stage the ovum is mature and ready for the completion of fertilization, the sperm having already entered the cytoplasm of the oöcyte. (The events of fertilization are described on page 241.)

The mature human ovum is the largest cell produced by the body, though it is barely visible to the unaided eye, averaging 0.13 mm. in diameter. It contains a large spherical nucleus within which is a *linin net* with scattered granules of *chromatin*, and a large *nucleolus*. The cytoplasm is filled with granules of *deuterooplasm* or *yolk*. Surrounding the cytoplasm is a thick membrane, striated in appearance, the *zona pellucida*. Beneath the *zona pellucida* is the clear *perivitelline space*.

Surrounding the ovum are cells from the follicle which form the *corona radiata*, from which fine protoplasmic processes extend through the *zona pellucida*. These carry nutritive materials to the ovum.

SPERMATOGENESIS. Sperms develop within the seminiferous tubules of the testes. In spermatogenesis there are five stages, as follows:

1. *Spermatogonia*. These are generalized cells located at the periphery of the seminiferous tubule. They increase in number by mitosis. Some remain as stem cells; the others migrate centrally, increase in size, and become primary spermatocytes.

2. *Primary spermatocytes*. The chromosomes unite in pairs (*synap-*

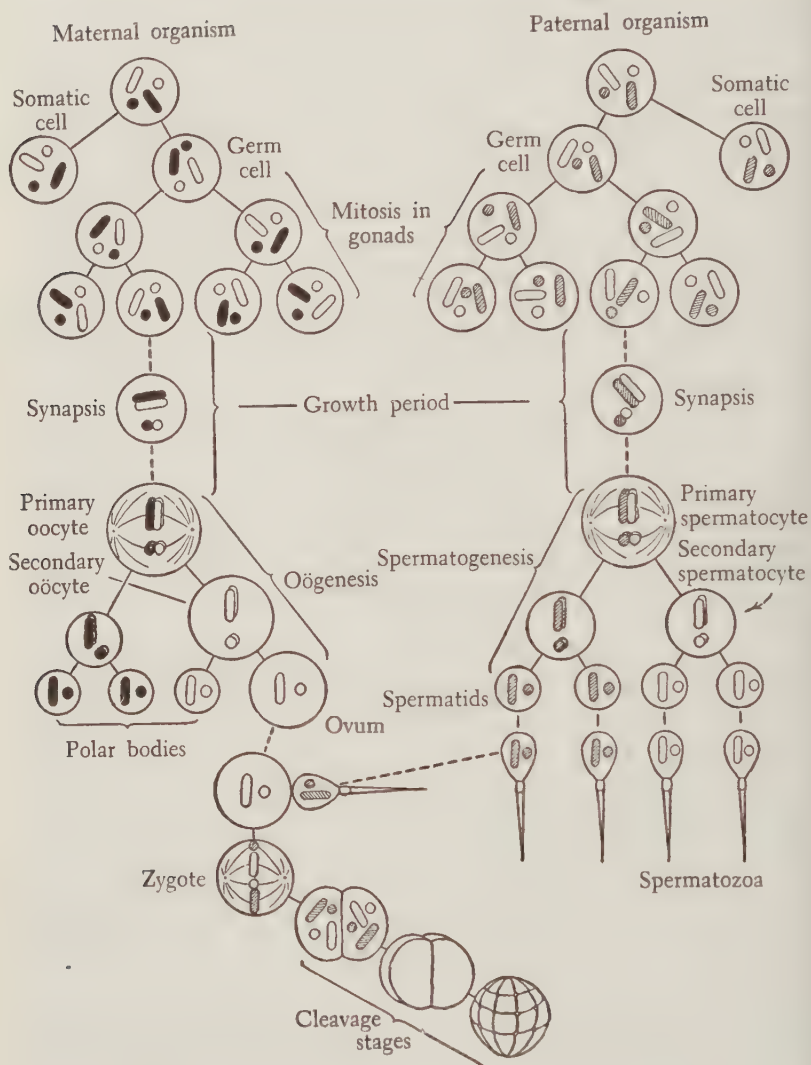


Fig. 81. Diagram illustrating maturation or gametogenesis (oögenesis in female, spermatogenesis in male) and the stages of embryogeny in animals. Also illustrated is the continuity of chromosomes from the gametes which form two parents, through the germ cells in the gonads of these individuals, to the embryo which is their progeny. Reduction division (meiosis) is represented here as occurring during first maturation division; it may occur during the second maturation division instead. (From Alexander, *Biology*, College Outline Series, copyright 1954, by Barnes & Noble, Inc.)

sis), and each spermatocyte divides by meiosis into two *secondary spermatocytes*, each with 23 chromosomes (one-half the normal diploid number of chromosomes).

3. *Secondary spermatocytes*. The primary spermatocytes divide by mitosis to form cells called *spermatids*, two for each spermatocyte. Each spermatid has a reduced number of chromosomes.

4. *Spermatids*. Each spermatid undergoes a series of changes by which a typically nonmotile cell becomes modified into a motile cell. This is accomplished through the development of a tail or *flagellum*.

5. *Spermatozoa*. These are the mature male germ cells. Each consists of three regions: head, middle piece or body, and tail. The *head* has a nuclear portion containing the chromatin material; it is covered by a *head cap*. Between the head and the middle piece is a *neck* (containing a *centrosome*, which is important in cell division). The *middle piece* contains a *spiral sheath* or *capsule* surrounding an *axial filament* which continues into and forms the principal part of the *tail*. The capsule surrounds the filament except at its extreme tip, which forms a *naked end-piece* or *terminal filament*.

Sperms average 0.05 mm. in length (about one-third the diameter of the ovum). In volume the ovum exceeds the sperm about 85,000 times. While they are in the seminiferous tubules and sperm ducts, spermatozoa are not actively motile. In the ejaculate they become actively motile; the *prostatic secretion* contains the activating factor.

Chromosomes, Genes, Twins. The processes of maturation serve a two-fold function: (1) to develop cells capable of performing the necessary reproductive functions (that is, in the sperm the function of finding an ovum and penetrating it, and, in the ovum, the function of storing a reserve supply of nutrient substances to provide energy for early development); and (2) to reduce the chromosome number by one-half, by which means the chromosome number, being restored to normal at fertilization, remains constant in each generation.

The chromosomes contain *genes* or *hereditary factors*, which are transmitted from one generation to the next. Genes appear to be arranged in a lineal order in each chromosome. They are the factors which, by interaction with the environment, largely condition the development of an individual. In short, an individual is what he is because of (1) the hereditary factors or genes which he receives from the egg and the sperm, and (2) the environment in which the genes undergo development and exert their effects.

The transmission of hereditary traits follows certain general laws or principles which were established by Mendel in 1865. These include the principles of segregation and independent assortment which, with modifications, form the basis of the modern chromosome theory of heredity.

The reduction of the number of chromosomes from the *diploid* number found in somatic cells to the *haploid* number found in reproductive cells results in the production of germ cells which differ not only in quantity of chromosomes but in quality as well; that is, they contain chromosomes that are unlike in their genetic (genic) make-up. In the formation of germ cells, the chromosomes are distributed at random, with the result that it is probable that no two eggs or sperms are ever exactly alike in their genic constitution. When two individuals are very much alike, as in the case of *identical twins*, it is assumed that they are *monozygotic* (developed from one zygote). *Fraternal twins*, usually not more alike than ordinary brothers and sisters, are assumed to develop from two ova which are fertilized by different sperms and develop at the same time.

Determination of Sex. Chromosomes play a significant role in the determination of the sex of the individual. Before reduction division, the chromosome complement consists of 46 chromosomes, arranged in 23 pairs. In the human oöcyte, these include 22 pairs of *autosomes* (containing genes for body characteristics) and 1 pair of *sex chromosomes* (designated XX). After the reduction division, each mature ovum contains 22 + X chromosomes. In the male, spermatocytes as well as all the somatic cells, contain 22 pairs of autosomes, plus 2 sex chromosomes, designated X and Y. In the process of maturation, two kinds of sperm are produced, one-half containing 22 + X and one-half 22 + Y. These two types are designated "X sperms" and "Y sperms." An ovum is fertilized by one or the other of these types. If an X-containing sperm unites with the ovum, the resulting zygote will contain 22 pairs of autosomes plus XX chromosomes; this zygote develops into a *female*. If the ovum is fertilized by a sperm containing a Y chromosome, the resulting zygote develops into a *male*. From this it is seen that the chromosome make-up of the zygote determines the sex of the individual.

COPULATION (COITION, COITUS)

After the sex cells (also called *gametes*) are formed, the next essential step in the process of reproduction is to bring them together. If the ovum is not fertilized within a few days after it is discharged from the ovary, it disintegrates. Among mammals, fertilization takes place within the body of the female. The organs of copulation transfer sperms from male to female. These are the *penis* in the male, the *vagina* in the female. In most mammals, mating occurs only when the female is in a receptive state (the *estrous period*), which usually occurs at the time of ovulation. (Lower animals are said to be "in heat" during this period.) In primates, including man, there is no definite period of receptivity, and mating may occur at any time during the

menstrual cycle. Ovulation takes place about halfway between the menstrual periods, and at this time conception is most likely to occur.

•Orgasm. During copulation the penis is introduced into the vagina, and mechanisms are brought into play which bring about discharge, or ejaculation, of semen. Associated with this discharge the male experiences a brief period of paroxysmal emotional excitement called an *orgasm*. An orgasm may also occur in the female, but without any associated discharge. During sexual activity all glands involved in the reproductive system are stimulated to greater activity.

Movement of Sperms. Spermatozoa are deposited in the upper end of the vagina in the region of the isthmus of the cervix. By lashing movements of the tail, they pass through the cervical canal into the cavity of the uterus, progressing at a rate of approximately 1.5 mm. per minute. In the absence of any directive stimulus, they tend to swim aimlessly. In the uterus the downward beating of the cilia tends to direct the sperms in the direction of the uterine tubes; as the sperms enter the tubes, their own movement, supplemented by segmental muscular contractions of the uterine tube, eventually brings them to the fimbriated portion, where fertilization usually occurs.

Viability of Sperms. It is not definitely known how long a sperm may live in the female genital tract, but there is evidence that they may survive as long as 14 days. The viability, or fertilizing power, is, however, believed to be limited to one or two days. Factors that limit their life and reduce their period of viability are: the high body temperature of the female, acidity of the vagina, and the phagocytic activity of leucocytes.

FERTILIZATION, SEGMENTATION, IMPLANTATION

The next steps in reproduction comprise fertilization, segmentation, and implantation.

Fertilization of the Ovum. The penetration of the ovum by a sperm and the fusion of the male and female pronuclei constitute *fertilization*. This accomplishes two ends: (1) it initiates the developmental processes in the ovum, and (2) it brings into the ovum the male hereditary particles or genes. In some of the lower animals, ova may develop without fertilization, a process known as *parthenogenesis*, or 'virgin birth.' Experimentally, ova have been removed from some of the lower mammals (rabbits, for example) and development has been initiated by subjecting the egg to certain salt solutions. After development has begun, these ova have been placed in uteri of normal animals and further development has proceeded normally. In mammals, however, this does not normally occur; in man, parthenogenetic development of ova has never been demonstrated.

Although details of fertilization of a human ovum are unknown, the

process is believed to be similar to that which occurs in other primates, in the mouse, and in the rabbit, for each of which the details are well known. A spermatozoön reaches the ovum by random movements; it is doubtful that chemical substances produced by the ovum have any attractive influence on the sperm. Semen contains an enzyme, *hyaluronidase*, which dissolves the intercellular material between the cells of the corona radiata still adhering to the ovum. Propelling themselves through the remains of the corona and the zona pellucida, sperms reach the surface membrane of the ovum. Tail movements cease and the successful sperm is drawn into the protoplasm of the egg. The head migrates toward the center of the egg, enlarges, and becomes the *male pronucleus*. The ovum completes the second maturation division, throwing off a second polar body. The *female pronucleus* now approaches the male pronucleus, and the nuclear membranes disappear. The chromatin of the nuclei forms two groups of homologous chromosomes which arrange themselves in an equatorial plate. Fertilization is now complete, and the ovum undergoes the first mitotic division, producing two daughter cells, each of which receives one-half of each chromosome contributed by the sperm and the ovum.

Segmentation and Implantation of the Ovum. Fertilization initiates the process of cell division or *segmentation*. By a series of mitotic divisions the zygote divides into 2 cells, then 4, 8, 16, 32, 64, and so on until it consists of a spherical mass of cells called a *morula*. While this is occurring, the morula moves slowly through the uterine tube and enters the uterus. Within the morula, a cavity begins to develop. This cavity enlarges until the whole comes to consist of a single layer of cells, the *trophoblast*, from which an *inner cell mass* projects centrally. The embryo develops from the inner cell mass; the trophoblast develops into structures concerned with nutrition of the embryo. At this stage the embryo is known as a *blastocyst*.

The inner cell mass gives rise to two cavities within its substance: the *amniotic cavity* and the *yolk sac* (*archenteron*). The yolk sac in humans does not contain any yolk substances; it is a vestigial structure which loses its connection with the body about the sixth week, after which it degenerates. The amniotic cavity is lined with a single layer of cells, the *ectoderm*; the yolk sac with a single layer, the *entoderm*. These constitute the two *primary germ layers*. Between the two cavities lies the *embryonic disc*, from which the embryo proper develops.

At about this stage, a third germ layer, the *mesoderm*, makes its appearance. Its cells come to occupy the space between the ectoderm and entoderm of the embryonic disc. It also forms a thin layer surrounding the amniotic cavity and yolk sac, and the lining of the trophoblast. The trophoblast and its inner lining of mesoderm now constitute the *chorion*, which becomes an important embryonic membrane.

The cavity of the chorion is filled with a fluid, and the entire structure is called the *chorionic vesicle*. At this stage the developing ovum passes from the uterine tube into the uterus.

The endometrium of the uterus is at this time in the *premenstrual* or *secretory phase* and ready to receive the embryo. At about the 8th or 9th day the blastocyst, on coming into contact with the endometrium, embeds itself in the uterine mucosa. This is the process called *implantation*. It is accomplished by the cytolytic or cell-dissolving action of the trophoblast cells, probably through the production of enzymes by which the maternal tissue is dissolved. Now small finger-like processes, the *chorionic villi*, grow out from the chorion. They develop into complex tree-like structures between which are *intervillous spaces*. These develop into cavities, the *blood lacunae*, which fill with maternal blood. Blood vessels from the embryo grow out into the villi, and through these structures the embryo receives its nourishment. The uterine tissue at this time completely encloses the developing embryo.

DEVELOPMENT OF THE EMBRYO

The embryonic disc, which is suspended from the chorion by the *body-stalk*, now consists of three primary germ layers. On this area a longitudinal streak develops, known as the *primitive streak*, which marks the primary axis of the embryo. At the anterior end, the cells of the three layers form a mass known as the *primitive knot*. From this mass a rod of mesoderm cells grows forward and fuses with the endoderm beneath. The rod constitutes the *head process*, from which the future notochord develops. The *notochord* is the axial supporting structure of the embryo and the forerunner of the vertebral column. The embryo at this time consists of a flat disc of cells forming the roof of the large yolk cavity below and the floor of the amniotic cavity above. A narrow canal, the *neurenteric canal*, connects the two. The following seven steps in development should be noted:

1. The ectoderm thickens anterior to the primitive knot, to form the *neural plate*. On each side, *neural folds* arise, enclosing a *neural groove*. These fuse to form a closed *neural tube*, which constitutes the primordial brain and spinal cord.

2. The mesoderm on each side of the neural tube thickens and becomes divided into block-like segments, the *mesodermal segments* or *somites*. Sheets of mesoderm extend laterally and split into a thin outer *somatic* and an inner *splanchnic layer*. The space between the two sheets is the *coelom*, which forms the body cavity.

3. The anterior portion of the neural tube grows rapidly anteriorly, also expanding laterally and turning ventrally. By this process the endoderm of the yolk sac is folded in, to form a blind pouch, the

fore-gut, from which develops the anterior portion of the digestive tract. In a similar way, the *hind-gut* is formed in the posterior region; from it develops an evagination, the *allantoic stalk*, which pushes out into the body-stalk. The region between the fore-gut and the hind-gut, forming the roof of the yolk sac, constitutes the *mid-gut*.

4. On either side of the fore-gut, the mesoderm hollows out to form two tubes lined with endothelium. These tubes meet and form a double-walled structure which develops into the *heart*. In the embryo *blood* is formed first in masses of mesodermal tissue (*blood islands*) in the walls of the yolk sac. Later it is formed in lymphoid tissue (spleen, thymus, lymph nodes), and, finally, beginning about the third month, in the bone marrow. Blood vessels develop from spaces in the mesoderm.

5. The rapid increase in the size of the heart and the brain and the turning under of the posterior portion of the body constrict the yolk sac so that it becomes connected with the mid-gut by only a narrow tube, the *yolk-stalk*. Downward development of the brain carries with it the surface ectoderm which, in the region between the brain and the heart, comes into contact with the endoderm of the fore-gut to form the *oral membrane*. This forms the floor of an external invagination, the *stomodeum*, which gives rise to the mouth parts following rupture of the oral membrane.

6. In the posterior region, the end of the hind-gut becomes the *cloaca*, into which open the urinary and genital ducts and the allantoic diverticulum. An external depression, the *proctodeum*, is separated from the hind-gut by the *anal* or *cloacal membrane* and a ventral *urogenital sinus*. Evaginations from the fore-gut give rise to digestive glands (liver and pancreas) and the thyroid gland. The latter loses its connection with the gut and becomes an endocrine gland.

7. Each lateral mass of a somite differentiates into three regions: an upper portion, the *dermatome*, which gives rise to the dermis of the skin; a ventral portion, the *sclerotome*, which gives rise to the axial skeleton; and a lateral portion, the *myotome*, which gives rise to the skeletal muscles. Lateral to each somite is the *nephrotome*; it lies between the mesodermal segment and the somatic and splanchnic layers of mesoderm which enclose the coelom. From the nephrotome develop the urinary organs and their ducts. A rounded mass develops which projects into the dorsal portion of the coelom to form the *urogenital fold*, on the median side of which develops the *genital fold*, which gives rise to the reproductive organs and their ducts.

It can be seen that all embryonic organs comprising the future organs and systems of the body arise from one or another of the three primary germ layers forming the embryonic disc. The principal derivatives of each of the germ layers are given in the following table.

| ECTODERM | MESODERM | ENDODERM |
|---|--|--|
| <p><i>General Derivatives:</i> Nervous system, sense organs, mouth cavity, skin</p> <p><i>Specific Derivatives:</i> Epidermis of skin and its derivatives (hair, nails, and sebaceous, sweat, and mammary glands) Brain, spinal cord, ganglia, nerves Lens, conjunctiva, retina, external and internal ear Lining of buccal and nasal cavities and parts of the pharynx and the paranasal sinuses Epithelium of the salivary glands and enamel of the teeth Hypophysis cerebri Anus and distal portion of male urethra Medulla of adrenal gland</p> | <p><i>General Derivatives:</i> Muscular, skeletal, circulatory, excretory, and reproductive systems</p> <p><i>Specific Derivatives:</i> All muscle tissues (smooth, striated, cardiac) All connective tissues (bone, cartilage, ligaments, tendons) All circulatory organs (heart, blood and lymph vessels, lymphatic organs, blood and blood-forming organs) Excretory organs (kidney, ureter, trigone of bladder) Reproductive organs (testes, ductus deferens, seminal vesicles, ovaries, uterine tubes, vagina) Serous membranes (pleurae, pericardium, peritoneum) Pulp, dentine, and cementum of teeth Cortex of the adrenal gland</p> | <p><i>General Derivatives:</i> Digestive and respiratory systems, certain excretory and reproductive ducts</p> <p><i>Specific Derivatives:</i> Lining of alimentary canal (except terminal portions), including pharynx and derivatives (auditory tubes, tympanic cavity, thyroid, parathyroids) Epithelium of digestive glands and their ducts (liver, pancreas, gall-bladder, bile duct) Lining of respiratory organs (except nasal cavity), including larynx, trachea, bronchial tree, lungs Bladder (except trigone) Female urethra and vestibular glands Male urethra (proximal portion), prostate, and bulbo-urethral glands</p> |

FORMATION OF THE EMBRYONIC MEMBRANES AND PLACENTA

Included among the accessory embryonic structures which have to do with protection, nutrition, respiration, and excretion are: yolk sac, amnion, chorion, allantois, umbilical cord, and placenta.

The Yolk Sac. In lower animals (birds and reptiles) this structure is an important organ, for it contains yolk, the primary source of food for the embryo. In man, however, it is small and of little functional importance. Structurally, the entoderm of the yolk sac gives rise to the epithelium of the major portion of the digestive tract. Although (in contrast to lower animals) no yolk is yet contained in the yolk sac, an extensive vitelline circulation develops, connected with the embryo through a narrow *yolk-stalk*. Blood cells are first formed in the walls of the yolk sac.

This sac becomes incorporated into the umbilical cord and, about

the 6th week, the stalk loses its connection with the gut. The yolk sac continues to shrink but may persist up to the time of birth, at which time it is usually found between the amnion and the chorion. In some adults the proximal end of the yolk-stalk persists and forms a blind intestinal pouch called *Meckel's diverticulum*.

The Amnion. The amniotic cavity originates as a cavity in the inner cell mass. Its wall, a thin layer of ectoderm, to which later a layer of somatic mesoderm is added, develops into the amnion. It increases in size until it surrounds the embryo except at the attachment of the umbilical cord. It is filled with amniotic fluid, in which the embryo is suspended. At about the third month, the amnion completely fills the chorionic sac and becomes adherent to the chorion, with which it fuses.

The *amniotic fluid* forms a protective fluid envelope that surrounds the embryo, permitting freedom of movement and allowing for growth. At parturition, uterine pressure forces the amniotic sac into the cavity of the cervix, where it serves as a fluid wedge for dilatation of the cervix. The amnion is usually ruptured during childbirth, with resultant loss of the fluid (the "flow of waters"). Amniotic fluid serves to moisten, lubricate, and disinfect the birth canal or vagina. If the amnion fails to burst, however, the head of the new-born may be prevented covered by the amnion; this covering is the so-called *caul* or "veil."

While immersed within the fluid of the amniotic sac, the embryo is protected by a fatty deposit, the *vernix caseosa*.

The Chorion. The chorion is formed from the ectoderm of the trophoblast, to which is added an inner layer of mesoderm. Together, these form the wall of the primitive blastocyst. Projections develop from it to form the *primary villi*, which, in turn, give rise to *secondary villi*. These profusely branched structures extend into the uterine mucosa. In them develop branches of the umbilical blood vessels. The development of the chorion is closely related to the development of the placenta. (See page 247.)

Although the chorion is an enveloping and protective structure, its primary function is concerned with the nutrition of the embryo.

The Allantois. The allantois arises as a small diverticulum or out-pocketing of the hind-gut. It grows into the body-stalk as a small, narrow tube. Blood vessels accompany it in its development and vascularize the chorion. After about the 4th week, the allantois ceases to grow and persists only as a rudimentary thread-like structure in the umbilical cord. It is functionally of little importance.

In egg-laying vertebrates (such as birds and reptiles), the allantois develops into a large vesicular structure which completely envelops the embryo. It is highly vascularized and forms the lining of the shell,

where it functions as a respiratory organ. It also has excretory and nutritive functions.

The Umbilical Cord. As the embryo develops and the amniotic sac enlarges, the ventral unenclosed area of the embryo becomes reduced in size. This region, the *umbilicus*, is the point of junction between the embryonic and the extraembryonic tissues. Further development produces a tubular structure, the *umbilical cord*, which is actually a continuation of the body wall of the fetus, connecting distally with the fetal portion of the placenta. This cord encloses the yolk-stalk (and a portion of the embryonic celom surrounding it), the allantois, and the allantoic vessels; the last of these become the *umbilical arteries* and *vein*.

At birth the umbilical cord is a spirally twisted cord about 2 feet long and 20 mm. in diameter. It consists of an outer epithelial covering of ectoderm enclosing a loose type of embryonic connective tissue (mucous tissue or *Wharton's jelly*). Embedded in this tissue are the yolk-stalk (and, in the early embryo, its vitelline vessels), the allantois, two umbilical arteries, and one umbilical vein.

Up to the 6th week, the embryonic gut protrudes into the celom of the cord to form a temporary umbilical hernia. As development proceeds, the gut is gradually withdrawn and the cavity of the cord disappears. The yolk-stalk disappears, and the allantois persists as a solid strand of tissue.

The Decidual Membranes. The mucosa of the maternal uterus comes into so intimate a relationship with the embryonic chorion that at birth there is an extensive sloughing off of the uterine lining. For this reason the endometrium of a pregnant uterus is known as the *decidua*.

When the chorionic vesicle implants in the uterine mucosa, it becomes completely embedded within the endometrium. As the embryo increases in size, it begins to form an elevation on the mucosal surface. Further growth causes it to protrude into the uterine cavity. At this time, three regions of the uterine mucosa can be differentiated: (1) *decidua parietalis* (the nonplacental lining of the uterus), the portion of the mucosa that has no direct connection with the embryo; (2) *decidua capsularis*, the portion which forms a thin covering on the free surface of the chorion; and (3) *decidua basalis*, the portion between the chorion and the muscular wall of the uterus.

The Placenta. Following implantation, villi develop over the entire surface of the chorionic vesicle, but, after the vesicle begins to protrude into the uterine cavity, the villi on the surface facing the uterine cavity (i.e., that covered by the decidua capsularis) begin to atrophy, leaving a smooth surface called the *chorion laeve*. The villi in the region of the decidua basalis undergo extensive development and form

the *chorion frondosum*, which constitutes the fetal part of the placenta, the decidua basalis forming the maternal part.

Umbilical arteries carry blood from the embryo to the villi of the chorion frondosum. The villi are surrounded by maternal blood occupying the *intervillous spaces* or *lacunae*. The blood of the fetus and that of the mother circulate in separate channels. Blood bathes the villi in a way similar to that of water in the soil bathing the roots of plants. Substances which can diffuse through cellular membranes pass from one to the other; consequently, some substances of the mother's blood diffuse into the blood of the fetus. Among these are nutritive materials, oxygen, hormones, and antibodies. Coincidentally, substances in the blood of the fetus diffuse into the mother's blood, among them waste products such as urea, carbon dioxide, and water. There is, however, *no intermixture of fetal and maternal blood*. Red blood cells, being 0.007 mm. in diameter, are far too large to pass through the placental filter.

The *mature placenta* is a large discoid structure averaging 6 to 7 inches in diameter and about 1 inch in thickness. In the uterus it is concave; the umbilical vessels enter on the concave side. At its margin there is a membrane which is a composite of several structures, namely, the decidua parietalis, decidua capsularis, chorion laeve, and amnion. The uterine surface of the mature placenta is divided into irregular regions or lobules called *cotyledons*.

PREGNANCY, PARTURITION, LACTATION

The final steps in reproduction comprise pregnancy, parturition, and lactation.

Pregnancy and Parturition. *Pregnancy* is the state of the female from time of fertilization of the ovum to childbirth. *Parturition* is the

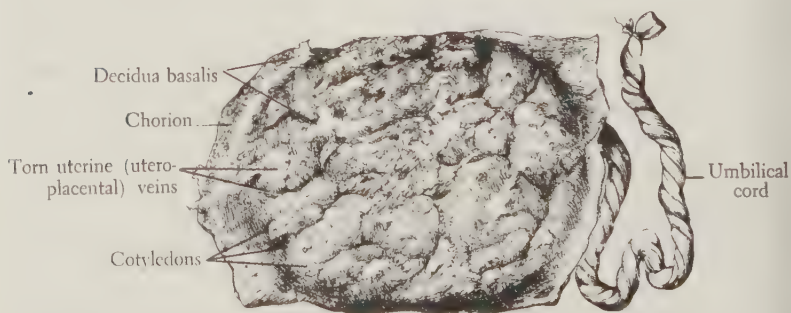


Fig. 8.2. Uterine surface of placenta at full term. (Reprinted with permission of The Macmillan Company from Toldt. *Atlas of Human Anatomy*, 1948.)

process of giving birth to the child, beginning normally with the first uterine contractions that lead to the expulsion of the newborn. *Lactation* is the process of secreting milk for the nourishment of the newborn.

Pregnancy. The state of pregnancy, also called *gestation*, is firmly established after implantation. The corpus luteum persists and becomes the *corpus luteum of pregnancy*, follicle formation is inhibited, and menstruation ceases to occur. In fact, for practical purposes, the period of "confinement" (pregnancy) is calculated on the basis of first day of the last menstrual period. The procedure is to take this day, count back 3 months, and add 7 days. From the resultant date, then, the time of birth can be estimated. The development of the fetus, within the uterus (*intrauterine* or *prenatal life*) consumes approximately 266 days. The following are the periods of intrauterine development:

PERIOD OF THE OVUM. This, the pre-embryonic period, extends from the time of fertilization to the time of implantation, a period of 8 to 10 days. During this period, segmentation occurs, with the developing zygote becoming differentiated into embryonic and extra-embryonic portions, and the primary germ layers being established.

PERIOD OF THE EMBRYO. This extends from the end of the first period, at about the 14th day to the end of the second month, or approximately 48 to 50 days. By the end of this period, the embryo has begun to assume a "human" appearance, and the rudiments of all the organ systems have developed. Some of the changes taking place during the embryonic period are:

1. *Change in general body form.* The body frame becomes straighter and most nearly erect. The dorsal convexity that is prominent in early embryos is lost.

2. *Development of the face and neck.* This takes place between the 5th and 8th weeks and is closely related to the development of the *branchial arches*, elevated regions which appear on the lateral surfaces of the face and neck. The branchial arches, separated by *branchial grooves*, correspond to the gill arches characteristic of aquatic forms, such as fishes. In these lower forms, they support gills, which serve as respiratory organs, the water flowing through the *clefts* separating the arches. In man, five arches separated by four external branchial grooves make their appearance. On the inside of the pharynx, in positions corresponding to the four grooves, are outpocketings, the *pharyngeal pouches*. These are lined with endoderm. Through modifications of these arches, the principal parts of the neck and face are developed. The first branchial groove constitutes the primordium of the external ear. The first pharyngeal pouch differentiates into the Eustachian tube and the tympanic cavity of the middle ear.

3. *Development and retrogression of the tail.* A tail develops, becoming prominent about the 6th week, after which it retrogresses and disappears.

4. *Alterations in the ventral portion of the body.* In early embryos, the heart and liver form a prominent ventral bulge. This structural characteristic continues until about the 8th week, when the gut begins to occupy the major portion of the abdominal region.

5. *The umbilical cord develops*, incorporating within itself the yolk-stalk and the body-stalk.

6. *The external genitalia appear*, representing the "indifferent stage" in sexual development.

7. *Limb buds appear*, and digits become well differentiated by the end of this period.

8. *Bone begins to appear*; centers of ossification develop.

9. *The nervous and muscular systems develop* to the extent that spontaneous movements can be initiated. Sense organs (eye, ear, and olfactory pit) make their appearance.

PERIOD OF THE FETUS. This extends from the beginning of the 3rd month to parturition. Some of the changes that occur during this time are:

In the 3rd month: The head, which is very large in early embryos, becomes relatively smaller; limbs become longer; nails appear; eyelids fuse. The intestine is withdrawn from the umbilical herniation into the body cavity. The external genitalia differentiate to the extent that sex can be distinguished. Centers of bone formation become numerous.

In the 4th month: The fetus appears distinctly "human." Hair appears on head and body. Bones become distinctly indicated. Sense organs (eye, ear, nose) assume typical forms.

In the 5th month: The hair coat (*lanugo*) is present. Blood formation in the bone marrow begins.

In the 6th and 7th months: The body form becomes better proportioned; the body has a wrinkled appearance.

In the 8th month: The fetus reaches the age of *viability*, that is, it is capable of living if it should be born prematurely. (With the aid of incubators, however, fetuses born with as little as 5 months of intra-uterine life and weighing only $17\frac{3}{4}$ ounces have survived.) Testes descend into the scrotum. Subcutaneous fat is deposited, and the body becomes plumper and smoother.

In the 9th and 10th months: Growth continues; additional fat accumulates. The *lanugo* is shed. Limbs become plumper, and nails extend to the tips of the digits. The embryo is now at *full term* and weighs on the average about 7 pounds.

Maternal Changes during Pregnancy. While the foregoing changes are taking place in the embryo and fetus, correlated changes are oc-

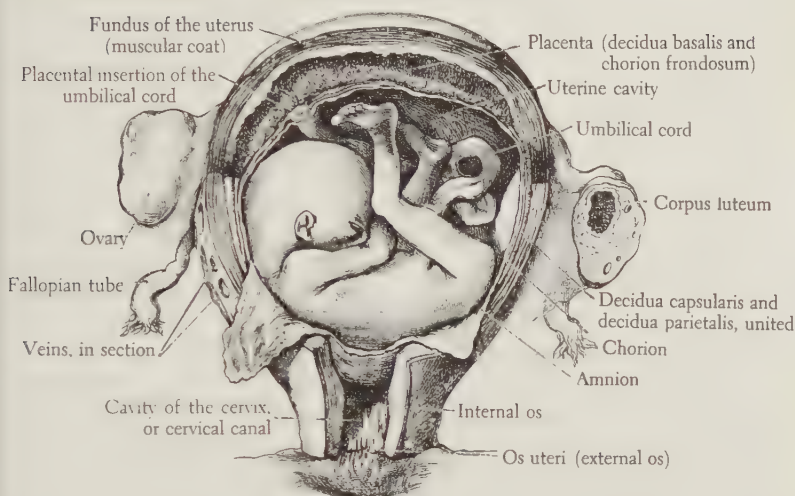


Fig. 8-3. Uterus, sixth month of pregnancy, opened by removal of posterior wall. Fetus, with membranes and placenta, in transverse section. (Reprinted with permission of The Macmillan Company from Toldt, *Atlas of Human Anatomy*, 1948.)

curring in the mother. During the period of the ovum, the chorionic vesicle, containing the embryo, becomes embedded within the uterine mucosa. During the period of the embryo, the vesicle has increased in size and fills the cavity of the uterus. By this time, the placenta has become established. As the fetus grows, the uterus likewise further increases in size and in weight. The *nonpregnant uterus* is about $2\frac{1}{2}$ inches in length, weighs about 50 gm., and has a capacity of 2 to 5 cc. The *pregnant uterus at full term* is about 20 inches in length, weighs about 1000 gm., and has a capacity of 5000 to 7000 cc.

With increased size, uterine muscles hypertrophy, the muscle cells becoming longer and increasing in number. The blood supply to the uterus is also greatly increased.

Until about the 4th month, the uterus with its contained fetus occupies space only within the pelvic cavity. After this time, an increase in size causes it to push upward into the abdominal cavity, where it brings about considerable displacement of the viscera. The body wall becomes distended and the skin on the face and neck may acquire a yellowish-brown pigment, the "mask of pregnancy." Mammary glands enlarge with the development of their secretory tissue. Posture changes come about, and the pubic symphysis and sacroiliac joints become softer. Changes in bone and teeth may occur, especially if there is a

calcium deficiency in the diet. Kidney function is increased, and disorders of urination often arise owing to pressure on the bladder.

Parturition (Childbirth). About 280 days after the onset of the last menstrual period before pregnancy, the fetus is at *full term* (sometimes described merely as "at term") and ready to be expelled from the body of the mother. The process of expulsion is called *parturition* or *labor*.

DURATION OF LABOR. The average duration of labor in the primiparous woman (pregnant with first child) among whites is 16½ hours, among Negroes 17½ hours. Among multiparous women (those who have previously borne one or more children in as many pregnancies) these figures are, respectively, 11 and 12½ hours.

Parturition is divided into three stages:

First Stage of Labor. Contractions of the uterus bring on the first "labor pains." Repeated contractions force the amniotic sac into the cervix, bringing about its dilatation, which permits the head of the fetus to enter the cervical canal and the upper end of the vagina. This usually takes about 6 hours, though in some mothers the time is much shorter and in others it is longer. The amnion usually ruptures at the point, the escaping amniotic fluid serving to moisten and lubricate the birth canal.

Second Stage of Labor. This period extends from the time of complete dilatation of the cervix to, and including, the expulsion of the fetus. It may last several hours. Uterine contractions and concomitant pains occur at much shorter intervals and are more severe. Contractions of the abdominal muscles assist the uterus in expelling the fetus. Following delivery of the child, the umbilical cord is ligated near the umbilicus, then severed. The uterus continues to contract, expelling the remaining portion of the amniotic fluid.

Third Stage of Labor. After a lull, uterine contractions resume, and the expulsion of the *placenta* ("afterbirth") takes place. This may occur within a short time after delivery of the new-born (20 to 30 minutes later) or not for some hours. The uterus then continues to contract, serving to close the ends of ruptured blood vessels and to arrest the flow of blood. The processes of this stage are accelerated when the baby is put to suck at the mother's breast immediately after birth.

Lactation. The secretion of milk by the mammary glands for nourishment of the young is called *lactation*. Following implantation, collapsed alveoli of the mammary glands enlarge and expand. New branches grow out from the ducts and develop into new alveoli. As the secreting tissue increases, the interstitial tissue becomes compressed and fatty tissue disappears. Toward the end of pregnancy, secretion begins and *colostrum* appears. This is a watery fluid which differs from

milk in the small amount of fat it contains and in the presence of *colostrum corpuscles* (believed to be phagocytic cells distended with fat particles). Extremely high in protein content, colostrum is believed to contain many substances which give the child immunity to the most common infectious diseases during the first few months of life. Colostrum disappears on the second or third day after delivery and is replaced by the secretion of true milk.

HUMAN MILK VERSUS COW'S MILK. Milk is an emulsion of fat particles suspended in a watery fluid containing proteins, sugar (especially lactose), and inorganic salts. A comparison of human milk and cow's milk is seen in the following table:

| <i>Substance</i> | <i>Human Milk</i> | <i>Cow's Milk</i> |
|------------------|-------------------|-------------------|
| | (Per Cent) | |
| Water | 88.3 | 87.3 |
| Inorganic salts | 0.2 | 0.7 |
| Protein | 1.5 | 3.8 |
| Fat | 4.0 | 4.0 |
| Sugars | 6.0 | 4.5 |
| Reaction | Alkaline | Acid |

Human milk is regarded as definitely superior to cow's milk or other foods in the following respects: (1) It is cleaner and freer from bacteria. (2) Its composition varies during the first few weeks of lactation, in accordance with the varying needs of the infant. (3) Its protein is principally soluble lactalbumin instead of the relatively insoluble caseinogen of cow's milk. The curd formed in the stomach from human milk is therefore less dense and is more readily digested. (4) The fat is in a more finely emulsified form, and there is a smaller proportion of fatty acids. (5) The percentage of lactose is higher. (6) Immune bodies from the mother's blood induce a greater degree of immunity in the infant. (7) Breast-fed babies, in contrast to bottle-fed babies, suffer less frequently from disturbances of the gastrointestinal tract (diarrhea, for example) and they recover more quickly from postnatal birthweight loss.

SECRETION OF MILK. The average yield of milk in the human nursing mother is from 600 to 800 gm. per day, but three to four times these amounts may be yielded over a long period without detrimental effects. Because milk is being constantly secreted in the period of lactation, repeated suckling by the infant or artificial removal is necessary. If the milk is not removed, secretory activities cease and the mammary glands undergo involution. Milk will continue to be secreted as long as the infant suckles, usually a period of 8 to 9 months. The gradual substitution of other foods for breast milk and the cessation of breast feeding constitute *weaning*.

Sucking by the infant aids in the involution of the uterus, gives the mother greater pleasure in her offspring, and plays an important role in the psychological development of the infant and mother.

POSTNATAL DEVELOPMENT AND LATER STAGES OF LIFE

The life of the individual following birth is termed *postnatal* or *extrauterine* development. This usually applies to life through the end of infancy, and may even refer to early childhood. The following is a chronological analysis of the periods of life, including "postnatal development":

1. *Period of the new-born*. Also called the *neonatal period*, this extends from birth to about the end of the first month.

2. *Infancy*. This extends from the end of the first month to about the end of the first year or to the time when an erect posture is assumed (on the average, about the 16th month).

3. *Childhood*. Extends from infancy to puberty. *Early* childhood, the "milk-tooth period," lasts from years 1 to 6; *middle* childhood, the "permanent-tooth period," from years 6 to 10; *late* childhood, or the "prepubertal period," from age 10 to puberty (13 to 15 years in males, 12 to 14 years in females).

4. *Puberty*. This stage of life is commonly identified in females with the first menstruation (*menarche*), about the middle of the 14th year, in male toward the end of the 15th year. Puberty should not, however, be identified with a specific event; rather, it should be regarded as a period of gradual development extending through two-thirds of the period of adolescence. During this period the sex organs become functional and secondary sex characteristics develop.

5. *Adolescence*. This period extends from puberty (which is extremely variable) to about the 21st year in females, the 24th year in males.

6. *Maturity*. *Early* maturity lasts from the end of adolescent period to about the 35th year, *later* maturity from the 35th to the 55th or 60th year.

7. *Terminal age*. This is the general term for the period of life following later maturity. *Senility* carries with it the connotation of a degree of enfeeblement or regressive personality changes.

ABNORMAL DEVELOPMENT OF FETUS

A considerable degree of variation occurs in the development of the human body. Whenever the organism as a whole or an individual part deviates from the normal range of variation, resulting in malformation, the condition is referred to as an *anomaly*. If the fetus as a whole is grossly malformed, it is called a *monster*. The study of abnormal development constitutes the science of *teratology*.

The Nature of Fetal Anomalies. Abnormalities may be functional or structural. Among functional abnormalities are conditions such as abnormal protein metabolism, photophobia (abnormal sensitivity to light), colorblindness, and hemophilia. Structural anomalies fall into the following general types:

1. *Absence of an organ or a part* (e.g., absence of a finger, an arm, or an external ear).

2. *Developmental arrest*, in which only partial development occurs (e.g., dwarfism, infantile uterus).

3. *Developmental excess*, in which growth or development is exaggerated (e.g., gigantism, extra digits, or hypertrophy of the clitoris).

4. *Failure to atrophy*, in which an embryonic structure which normally atrophies persists. Examples are persistence of a tail, a pupillary membrane, the hyaloid artery in the vitreous body of the eye, and Meckel's diverticulum of the ileum (which is the persistent end of the embryonic yolk-stalk).

5. *Failure of fusion*, in which paired embryonic parts which normally fuse fail to do so, resulting in conditions such as double uterus or cleft palate.

6. *Fusion*, in which parts normally paired are united into a single structure (as in horse-shoe kidney).

7. *Splitting*, in which parts normally single are paired or split (e.g., a ureter).

8. *Failure to subdivide* (e.g., fused digits).

9. *Persistence of embryonic ducts or openings which normally close* (e.g., a patent ductus arteriosus, persistent foramen ovale, and cervical fistula).

10. *Stenosis*, or abnormal narrowing, of a duct or opening (e.g., pyloric stenosis, aortic stenosis).

11. *Abnormal migration*, in which the normal shifting of an embryonic structure fails to occur (e.g., cryptorchidism) or migration of structures to abnormal positions, as in the case of parathyroids occurring in the thorax.

12. *Misplacement*, in which organs develop in abnormal positions (e.g., palatine teeth in the roof of the mouth, or transposition of viscera in which organs normally occurring on the right side appear on the left side of the body, in mirror-image position).

Causes of Abnormalities. Abnormalities are either inherited or acquired.

INHERITED ABNORMALITIES. These are the result of the action of the genes transmitted through the egg or sperm. Anomalies of this type tend to recur generation after generation in a more or less definite pattern, following the laws of heredity. New characteristics may make their appearance as a result of mutations (spontaneous changes in the genes) or changes in chromosome numbers. The primary cause in each case is not known. Such changes have been produced experimentally in animals and plants by exposing the germ cells to X rays or radioactive substances.

ACQUIRED ABNORMALITIES. These are due to some environmental factor or influence which acts on the developing individual or a part of the organism. In the process of development, each organ or other structure passes through a *critical period*, at which time the growth rate is accelerated and differentiation processes are brought into play; the organs and tissues are markedly susceptible to any abnormal influences which are brought to bear upon them. In general, most abnormalities have their origin in the embryonic period (from the sec-

ond to the eighth week, inclusive), for it is then that all the organ systems come into existence from their respective germ layers and the fundamental structure of each organ is established. Some of the environmental factors which may modify embryonic development are: mechanical factors, radiation, chemical factors, and disease and disease organisms.

Mechanical Factors. Experimentally, forces such as pressure or constriction may modify the development of eggs outside the body, but the human embryo developing within the uterus seems to be remarkably free from the effects of such influences. Blows to the abdomen, unless of unusual severity, are unlikely to injure the fetus. However, a deficiency of *amniotic fluid* may result in distorted forms, such as compression babies.

Radiation. Tissues in which cells are multiplying rapidly are peculiarly susceptible to radiations of radioactive substances. Such tissues include the spermatogenic cells of the testes and the hemopoietic cells of the bone marrow. In a developing embryo, sub-lethal doses of X rays, radium and atomic radiations have been shown to be responsible for the development of anomalies.

Chemical Factors. These factors operating on human development obviously involve chemical substances in the mother's blood which are transmitted through the placenta to the fetus. Chemical substances known to influence fetal development include vitamins, hormones, and Rh antibodies.

Experimental work on laboratory animals has shown that a deficiency in *vitamin A* may bring about eye defects, diaphragmatic hernia, and abnormal kidneys; *riboflavin* deficiency may cause skeletal defects and cleft palate; deficiency in *vitamin B₁₂* may cause cranial abnormalities; and a deficiency in *folic acid* may cause a number of defects. In all experiments, the fetal death rate was above normal. Adequate vitamin intake is of special importance to pregnant women, and a greater daily allowances of all vitamins, especially those of the vitamin B complex, are recommended.

There is evidence that *hormones* produced by the mother's endocrine glands, especially the adrenal gland, have a considerable influence on the development and well being of the fetus. As the secretion of most hormones is either directly or indirectly under the influence of the nervous system, the mental state of a prospective mother may play an important role in the normal development of the fetus.

An Rh-negative woman bearing an Rh positive fetus, if she has been previously sensitized, may develop *antibodies* to the Rh factor. These, on entering the fetus through the placenta, will tend to destroy the blood cells of the developing fetus, with resulting death or serious illness of the fetus (*erythroblastosis fetalis*).

Disease and Disease Organisms. The *syphilis* organism may cross the placental barrier and infect the embryo, resulting in abnormalities of the bone or teeth. The number of stillbirths among syphilitic mothers is much higher than among nonsyphilitic mothers. *Rubella* (*German measles*) is a virus disease which, if acquired by the mother during the early months of pregnancy, usually results in abnormalities. In connection with this disease, the incidence of *congenital cataract* is unusually high, especially when the disease occurs during the second or third month of pregnancy; heart lesions, microcephaly, deaf mutism, and other defects have been noted.

TWINS AND TWINNING

A twin is one of two individuals developed within the uterus at the same time as a result of a single impregnation. Twins are of two types: *diovular* and *monovular*.

Diovular Twins. These are also called dizygotic, fraternal, or "false" twins. They result from the liberation and fertilization of two separate ova. They may be of the same or opposite sexes. Extra-embryonic membranes develop separately for each, though secondary fusion may occur. About 75 per cent of all cases of twinning belong to this type.

Monovular Twins. These are also called monozygotic, similar, duplicate, or identical twins, as both develop from a single, fertilized ovum which, at an early stage in development, divides into two masses each of which develops into a complete individual. This may occur as a result of (1) the development of two inner cell masses within the blastocyst or (2) the development of two organization centers within a single cell mass (or the division of a single organization center by budding or fission) to form two embryonic axes, each capable of developing into a complete embryo.

Anomalies. Malformations occur frequently among identical twins. The twins may develop unequally, resulting in individuals of unequal size. They may be conjoined and form a "double monster." The degree of fusion may be slight, involving only superficial tissues, or it may be extensive, involving visceral and skeletal parts. Sometimes, the separation of conjoined twins after birth is possible; in other cases, they remain united through life, as "Siamese twins."

In cases involving the splitting of the embryonic axis, the fission may be complete, with all parts of the body duplicated; or it may be partial, with some parts doubled, others single. The latter process accounts for the formation of two-headed babies or of babies with a single head and neck and a double trunk.

APPENDICES

APPENDIX A

SOME RECENT CHANGES IN TERMINOLOGY

Recent changes in anatomic terminology are indicated in the following list of 583 terms. The terms in bold type are those listed in the Basle Anatomical Nomenclature (BNA) of 1895. (Some important traditional terms listed below and referred to in this Outline can also be found in the Index.) The terms in regular type are the new equivalent terms approved by the Sixth International Congress of Anatomists in 1955. The terms in italic type are additional terms listed and discussed in 1955 by the International Nomenclature Committee.

- Ala cinerea** (trigonum nervi vagi)
- Amphiarthroses** (juncturae cartilagineae)
- Angulus acromialis* (subcutaneous bony point at lateral border of acromion)
- Angulus iridis** (angulus iridocornealis)
- Annulus inguinalis abdominis** (annulus inguinalis profundus)
- Annulus inguinalis subcutaneus** (annulus inguinalis superficialis)
- Ansa cervicalis* (loop of cervical plexus, innervating infrahyoid and geniohyoid muscles)
- Anulus inguinalis superficialis** (annulus inguinalis abdominis)
- Anulus inguinalis superficialis** (annulus inguinalis subcutaneus)
- Apertura mediana ventriculi quarti** (foramen Magendü)
- Apex vesicae** (**vertex vesicae**)
- Aponeurosis muscoli bicipitis brachii** (**lacertus fibrosus**)
- Appendix ventriculi laryngis** (sacculus laryngis)
- Arcus alveolaris** (**limbus alveolaris**)
- Arcus glossopalatinus** (arcus palatoglossus)
- Arcus iliopectineum* (iliopubic arch)
- Arcus palatoglossus** (**arcus glossopalatinus**)
- Arcus palatopharyngeus** (**arcus pharyngopalatinus**)
- Arcus palmaris profundus** (**arcus volaris profundus**)
- Arcus palpebralis** (**arcus tarseus**)
- Arcus pharyngopalatinus** (arcus palatopharyngeus)
- Arcus tarseus** (arcus palpebralis)
- Arcus venosus palmaris** (**arcus volaris venosus**)
- Arcus volaris profundus** (arcus palmaris profundus)
- Arcus volaris venosus** (arcus venosus palmaris)
- Area acustica** (area vestibularis)
- Area parolfactoria** (area subcallosa)
- Area subcallosa** (**area parolfactoria**)
- Area vestibularis** (**area acustica**)
- Arteria anonyma** (arteria brachiocephalica)

- Arteria auditiva interna** (arteria labyrinthi)
- Arteria brachiocephalica** (arteria anonyma)
- Arteria buccalis** (arteria buccinatoria)
- Arteria buccinatoria** (arteria buccalis)
- Arteria coeliaca** (truncus coeliacus)
- Arteria cremasterica** (arteria spermatica externa)
- Arteria deferentialis** (arteria ductus deferentis)
- Arteria ductus deferentis** (arteria deferentialis)
- Arteria frontalis** (arteria supratrochlearis)
- Arteria haemorrhoidalis inferior** (arteria rectalis inferior)
- Arteria haemorrhoidalis superior** (arteria rectalis superior)
- Arteria hypogastrica** (arteria iliaca interna)
- Arteria labyrinthi** (arteria auditiva interna)
- Arteria mammaria interna** (arteria thoracica interna)
- Arteria pulmonalis dextra** (ramus dexter a. pulmonalis)
- Arteria pulmonalis sinistra** (ramus sinister a. pulmonalis)
- Arteria radialis indicis** (arteria volaris indicis radialis)
- Arteria rectalis inferior** (arteria haemorrhoidalis inferior)
- Arteria rectalis superior** (arteria haemorrhoidalis superior)
- Arteria spermatica externa** (arteria cremasterica)
- Arteria spermatica interna** (arteria testicularis, arteria ovarica)
- Arteria subcostalis** (artery arising from back of thoracic aorta, with distribution like that of posterior intercostal arteries)
- Arteria supratrochlearis** (arteria frontalis)
- Arteria testicularis, arteria ovarica** (arteria spermatica interna)
- Arteria thoracica interna** (arteria mammaria interna)
- Arteria transversa scapulae** (arteria suprascapularis)
- Arteria volaris indicis radialis** (arteria radialis indicis)
- Articulatio atlanto-axialis mediana** (articulatio atlanto-epistrophica)
- Articulatio atlanto-epistrophica** (articulatio atlanto-axialis mediana)
- Articulatio mandibularis** (articulatio temporo-mandibularis)
- Articulatio mediocarpea** (joint between two rows of carpal bones)
- Articulatio subtalaris** (articulatio talocalcanea)
- Articulatio talocalcanea** (articulatio subtalaris)
- Articulatio temporo-mandibularis** (articulatio mandibularis)
- Articulationes digitorum** (articulationes interphalangeae)
- Articulationes interphalangeae** (articulationes digitorum)
- Auricula** (auris)
- Auris** (auricula)
- Axis** (epistropheus)
- Basis cerebri** (basis encephali)
- Basis encephali** (basis cerebri)
- Brachium conjunctivum** (pedunculus cerebellaris superior)
- Brachium pontis** (pedunculus cerebellaris medius)
- Bulbus penis** (bulbus urethrae)
- Bulbus urethrae** (bulbus penis)
- Bursa mucosa** (bursa synovialis)
- Bursa musculi trochlearis** (bursa synovialis trochlearis)
- Bursa subtendinea musculi tricipitis brachii** (bursa subtendineaolecrani)
- Bursa subtendineaolecrani** (bursa subtendinea musculi tricipitis brachii)
- Bursa synovialis** (bursa mucosa)
- Bursa synovialis trochlearis** (bursa musculi trochlearis)

- Calcaneus** (**corpus calcanei**)
- Canaliculus lacrimalis** (**ductus lacrimalis**)
- Canalis alimentarius** (**tubus digestorius**)
- Canalis analis** (**pars analis recti**)
- Canalis cervicalis uteri** (**canalis cervicis uteri**)
- Canalis cervicis uteri** (**canalis cervicalis uteri**)
- Canalis incisivus** (canal piercing anterior portion of bony palate)
- Canalis opticus** (**foramen opticum**)
- Canalis semicircularis anterior** (**canalis semicircularis superior**)
- Canalis semicircularis superior** (**canalis semicircularis anterior**)
- Capitulum** (term is used only for distal end of humerus)
- Capsula fibrosa, hepatis** (**capsula fibrosa perivascularis**)
- Capsula fibrosa perivascularis** (**capsula fibrosa, hepatis**)
- Caput angulare m. quadrati labii superioris** (**musculus levator labii superioris alaeque nasi**)
- Caput infraorbitale m. quadrati labii superioris** (**musculus levator labii superioris**)
- Caput zygomaticum m. quadrati labii superioris** (**musculus zygomaticus minor**)
- Carina trachea** (projection from last cartilage of trachea between origins of right and left principal bronchi)
- Cavum infraglotticum** (portion of larynx below rima glottidis)
- Cellulae anteriores** (small part of sinus ethmoidales, communicating with middle meatus)
- Cellulae ethmoidales** (sinus ethmoidales)
- Cellulae mediae** (small part of sinus ethmoidales, communicating with middle meatus)
- Cellulae posteriores** (small part of sinus ethmoidales, communicating with superior meatus)
- Cementum** (**substantia ossea**)
- Cervix** (a constricted portion; the neck, especially the lower portion of uterus)
- Clava** (**tuberculum nuclei gracile**)
- Collum** (used to denote entire neck of body)
- Columnae anales** (**columnae rectalis**)
- Columnae rectalis** (**columnae anales**)
- Comma tract** (**fasciculus semilunaris**)
- Commissura fornicis** (**commissura hippocampi**)
- Commissura hippocampi** (**commissura fornicis**)
- Condylus humeri** (distal end of humerus, including fossae olecrani, coronoidea and radialis, and trochlea and capitulum)
- Connexus intertendineus** (**junctura intertendineus**)
- Corpus calcanei** (**calcaneus**)
- Corpus cavernosum urethrae** (**corpus spongiosum penis**)
- Corpus ossi. ischii** (main portions or body of ischium; now includes ramus superior oss. ischii)
- Corpus restiforme** (**pedunculus cerebellaris inferior**)
- Corpus spongiosum penis** (**cavernous body of tissue in ventral portion of penis in median plane, traversed by urethra; corpus cavernosum urethrae**)
- Crista infratemporalis** (crest of bone separating facies temporalis of ala major of sphenoid bone into temporal and pterygoid portions)
- Crista medialis** (crest dividing fibula into two parts)
- Crista palatina** (transverse crest on inferior surface of lamina horizontalis of tibia or fibula)
- Crus anterius capsulae internae** (**pars frontalis capsulae internae**)
- Crus posterius capsulae internae** (**pars occipitalis capsulae internae**)

- Dentinum** (**substantia eburnea**)
- Diarthroses** (**juncturae synoviales**)
- Digitationes hippocampi** (**pes hippocampi**)
- Discus interpubicus** (**lamina fibrocartilaginica interpubica**)
- Ductuli biliferi** (ducts connecting interlobular ductules to right or left hepatic duct)
- Ductus excretorius, glandulae cowperi** (ductus glandulae bulbo-urethralis)
- Ductus glandulae bulbo-urethralis** (ductus excretorius, glandulae cowperi)
- Ductus lacrimalis** (canaliculis lacrimalis)
- Ductus semicircularis anterior** (ductus semicircularis superior)
- Ductus semicircularis superior** (ductus semicircularis anterior)
- Ductus submandibularis** (ductus submaxillaris)
- Ductus submaxillaris** (ductus submandibularis)
- Emissarium** (venae emissariae)
- Enamelum** (**substantia adamantina**)
- Epistropheus** (axis)
- Extremitas** (not used to denote a limb; extremitas now denotes only ends of pointed structure)
- Extremitas anterior** (**extremitas inferior**)
- Extremitas inferior, lienis** (anterior border of spleen; extremitas anterior)
- Extremitas posterior** (**extremitas superior**)
- Extremitas superior, lienis** (posterior border of spleen; extremitas posterior)
- Facies fibularis** (articular surface of fibula)
- Facies gastrica, lienis** (impressio gastrica)
- Facies glutea** (gluteal surface of ilium)
- Facies interlobares** (interlobular surfaces of lung)
- Facies renalis** (impressio renalis)
- Fascia cervicis** (**fascia colli**)
- Fascia clavipectoralis** (**fascia coracoclavicularis**)
- Fascia colli** (fascia cervicis)
- Fascia coracoclavicularis** (fascia clavipectoralis)
- Fascia dentata hippocampi** (gyrus dentatus)
- Fascia endothoracica** (fascia within thorax)
- Fascia spermatica interna** (**tunica vaginalis communis**)
- Fasciculus cerebellospinalis** (fasciculus spino-cerebellaris posterior)
- Fasciculus mammillothalamicus** (**fasciculus thalamomammilaris**)
- Fasciculus semilunaris** (**comma tract**)
- Fasciculus spino-cerebellaris posterior** (**fasciculus cerebellospinalis**)
- Fasciculus thalamomammilaris** (fasciculus mammillothalamicus)
- Fibrae cerebello-olivares** (tractus olivocerebellaris)
- Fibrae pontis profundae** (fibrae pontis transversae)
- Fibrae pontis transversae** (**fibrae pontis profundae**)
- Fissura calcarina** (sulcus calcarinus)
- Fissura cerebri lateralis** (sulcus lateralis)
- Fissura collateralis** (sulcus collateralis)
- Fissura hippocampi** (sulcus hippocampi)
- Fissura horizontalis cerebelli** (sulcus horizontalis cerebelli)
- Fissura parietooccipitalis** (sulcus parieto-occipitalis)
- Folliculi oöphori** (folliculi ovarici)
- Folliculi ovarici** (**folliculi oöphori**)
- Folliculus lymphaticus** (groups of lymphoid cells in mucous coats of gut and other areas; nodulus lymphaticus)

- Foramen ethmoidale anterius* (opening for anterior ethmoidal nerve and vessels along floor of cranial fossa)
- Foramen Magendü* (apertura mediana ventriculi quarti)
- Foramen opticum* (canalis opticus)
- Foramina sacralia anterior* (foramina sacralia dorsalis)
- Foramina sacralia dorsalis* (foramina sacralia anterior)
- Foramina sacralia pelvina* (foramina sacralia posterior)
- Foramina sacralia posterior* (foramina sacralia pelvina)
- Fossa incisiva* (median depression in anterior portion of inferior surface of bony palate)
- Fossa intercondylares, tibiae* (area intercondylares)
- Fossa malleoli lateralis* (fossa on medial aspect of lateral malleolus of fibula)
- Fossa navicularis, vestibuli vaginae* (fossa vestibuli vaginae)
- Fossa scaphoidea* (scapha)
- Fossa venae cavae, hepatis* (sulcus venae cavae, hepatis)
- Fossa vestibuli vaginae* (fossa navicularis, vestibuli vaginae)
- Fossulae tonsillares* (mouths of cryptae tonsillares)
- Fovea submaxillaris* (fovea submandibularis)
- Ganglion inferius, nervi glossopharyngei* (ganglion petrosum)
- Ganglion inferius, vagi* (ganglion nodosum)
- Ganglion jugulare* (ganglion superius)
- Ganglion nodosum* (ganglion inferius, vagi)
- Ganglion petrosum* (ganglion inferius, nervi glossopharyngei)
- Ganglion submandibulare* (ganglion submaxillare)
- Ganglion submaxillare* (ganglion submandibulare)
- Ganglion superius* (ganglion jugulare)
- Glandula lacrimalis* (glandula lacrimalis superior)
- Glandula lacrimalis superior* (glandula lacrimalis)
- Glandula mammaria* (mamma)
- Glandula submandibularis* (glandula submaxillaris)
- Glandula submaxillaris* (glandula submandibularis)
- Glandulae clausae* (glandulae sine ductibus)
- Glandulae sine ductibus* (glandulae clausae)
- Gyrus angularis* (pars media lobuli parietalis inferioris)
- Gyrus centralis anterior* (gyrus precentralis)
- Gyrus centralis posterior* (gyrus postcentralis)
- Gyrus dentatus* (fascia dentata hippocampi)
- Gyrus fusiformis* (gyrus occipitotemporalis medialis)
- Gyrus hippocampi* (gyrus parahippocampalis)
- Gyrus occipitotemporalis medialis* (gyrus fusiformis)
- Gyrus parahippocampalis* (gyrus hippocampi)
- Gyrus paraterminalis* (gyrus subcallosus)
- Gyrus postcentralis* (gyrus centralis posterior)
- Gyrus precentralis* (gyrus centralis anterior)
- Gyrus subcallosus* (gyrus paraterminalis)
- Hiatus saphenus* (fossa ovalis)
- Impressio gastrica* (facies gastrica, lienis)
- Impressio ligamenti costoclavicularis* (tuberositas costalis)
- Impressio renalis* (facies renalis)

- Incisura angularis* (angular depression in lesser curvature of stomach at pylorus)
- Incisura jugularis* (notch on manubrium of sternum)
- Incisura ligamenti teretis, hepatis* (*incisura umbilicalis, hepatis*)
- Incisura umbilicus, hepatis* (*incisura ligamenti teretis*)
- Indusium griseum* (layer of gray matter on superior surface of corpus callosum)
- Inscriptio tendinea* (intersectio tendinea)
- Intersectio tendinea* (*inscriptio tendinea*)
- Isthmus gyri cinguli* (*isthmus gyri fornicati*)
- Isthmus gyri fornicati* (*isthmus gyri cinguli*)
- Junctura intertendineus* (connexus intertendineus)
- Junctura synovialis* (*diarthrosis*)
- Juncturae cartilagineae* (*amphiarthroses*)
- Juncturae fibrosae* (*synarthroses*)
- Labrum acetabulare* (fibrocartilage along acetabulum of os coxae)
- Lacertus fibrosus* (aponeurosis musculi bicipitis brachii)
- Lamina fibrocartilaginica interpubica* (*discus interpubicus*)
- Lamina mucosa* (*tunica mucosa*)
- Lamina orbitalis* (*lamina papyracea*)
- Lamina papyracea* (*lamina orbitalis*)
- Lamina quadrigemina* (*tectum, mesencephali*)
- Laminae albae, cerebelli* (*laminae medullares*)
- Laminae medullares* (*laminae albae, cerebelli*)
- Ligamenta accessoria plantaria* (*ligamenta plantaria, artic. metatarsophalangeae*)
- Ligamenta accessoria volaria* (*ligamentum palmare, artic. metatarsophalangeae*)
- Ligamenta basium interossea* (*ligamenta metatarsae interossea*)
- Ligamenta basium, oss. metacarp., dorsalia* (*ligamenta metacarpea dorsalia*)
- Ligamenta basium, oss. metatarsalium, interossea* (*ligamenta metatarsae interossea*)
- Ligamenta capitulorum, oss. metacarp., transversa* (*ligamenta metacarpeum transversum profundum*)
- Ligamenta carpometacarpea palmaria* (*ligamenta carpo-metacarpea volaria*)
- Ligamenta carpo-metacarpea volaria* (*ligamenta carpometacarpea palmaria*)
- Ligamenta cuneonavicularia dorsalia* (*ligamenta naviculari-cuneiformia*)
- Ligamenta cuneonavicularia plantaria* (*ligamenta naviculari-cuneiformia plantaria*)
- Ligamenta intercarpea palmaria* (*ligamenta intercarpea volaria*)
- Ligamenta intercarpea volaria* (*ligamenta intercarpea palmaria*)
- Ligamenta intercostalia externa* (*membrana intercostalia externa*)
- Ligamenta intercostalia interna* (*membrana intercostalia interna*)
- Ligamenta metacarpea dorsalia* (*ligamenta basium, oss. metacarp., dorsalia*)
- Ligamenta metacarpeum transversum profundum* (*ligamenta capitulorum, oss. metacarp., transversa*)
- Ligamenta metatarsae interossea* (*ligamenta basium interossea*)
- Ligamenta naviculari-cuneiformia dorsalia* (*ligamenta cuneonavicularia dorsalia*)
- Ligamenta naviculari-cuneiformia plantaria* (*ligamenta cuneonavicularia plantaria*)
- Ligamenta plantaria, artic. metatarsophalangeae* (*ligamenta accessoria plantaria*)
- Ligamentum capitis femoris* (*ligamentum teres femoris*)

Ligamentum carpi dorsale (retinaculum musculorum extensorum)

Ligamentum carpi transversum (retinaculum musculorum flexorum)

Ligamentum costotransversarium (ligament connecting dorsal aspect of neck of rib to transverse process of vertebra above)

Ligamentum cruciatum atlantis (ligamentum cruciforme atlantis)

Ligamentum cruciatum cruris (retinaculum musculorum extensorum inferius)

Ligamentum interfoveolare (ligament on medial side of deep inguinal ring, connecting with transverse muscle and inguinal ligament)

Ligamentum laciniatum (retinaculum musculorum flexorum)

Ligamentum malleoli lateralis anterior (ligamentum tibiofibulare anterius)

Ligamentum malleoli lateralis posterior (ligamentum tibiofibulare posterius)

Ligamentum menisco-femorale anterius (anterior ligament of knee joint)

Ligamentum menisco-femorale posterius (posterior ligament of knee joint)

Ligamentum palmare, artic. metatarsophalangeae (ligamenta accessoria volaria)

Ligamentum pubocapsulare (ligamentum pubofemorale)

Ligamentum pubofemorale (ligamentum pubocapsulare)

Ligamentum quadratum (ligament connecting distal margin of radial notch of ulna to neck of radius)

Ligamentum teres femoris (ligamentum capitis femoris)

Ligamentum tibiofibulare anterius (ligamentum malleoli lateralis anterius)

Ligamentum tibiofibulare posterius (ligamentum malleoli lateralis posterius)

Ligamentum transversum cruris (retinaculum musculorum extensorum superius)

Limbus alveolaris (arcus alveolaris)

Linea arcuata (linea semicircularis)

Linea semicircularis (linea arcuata)

Lobi glandulae mammariae (lobi mammae)

Lobi mammae (lobi glandulae mammariae)

Lymphoglandulae auriculares posteriores (nodi lymphatici retroauriculares)

Lymphoglandulae bronchioles (nodi lymphatici bronchopulmonales)

Lymphoglandulae gastricae inferioris (nodi lymphatici gastrici dextrae)

Lymphoglandulae gastricae superiores (nodi lymphatici gastrici sinistri)

Lymphoglandulae hypogastricae (nodi lymphatici iliaci interni)

Lymphoglandulae mediastinales anteriores (nodi lymphatici mediastinales anteriores)

Lymphoglandulae mesocolicae (nodi lymphatici colici medii)

Lymphoglandulae sternales (nodi lymphatici sternales)

Lymphoglandulae subinguinales superficiales (nodi lymphatici inguinales profundi)

Maculae acusticae (maculae labyrinthi membranacei)

Maculae labyrinthi membranacei (maculae acusticae)

Mamma (glandula mammaria)

Margo anterior, lienis (margo superior, lienis)

Margo axillaris (margo lateralis)

Margo inferior, lienis (margo posterior, lienis)

Margo lateralis, uteri (margo uteri)

Margo medialis (margo vertebralis)

Margo posterior, lienis (margo inferior, lienis)

Margo superior, lienis (**margo anterior, lienis**)
Margo uteri (**margo lateralis, uteri**)
Margo vertebralis (**margo medialis**)
Mediastinum (**septum mediastinale**)
Medulla (**substantia medullaris**)
Membrana intercostalia externa (**ligamenta intercostalia externa**)
Membrana intercostalia interna (**ligamenta intercostalia interna**)
Membrana tympani (**tunica mucosa tympani**)
Membrum (now denotes a limb only; *extremitas* is used to denote ends of pointed structures)
Mesenteriolum appendicis vermiformis (**mesenteriolum processus vermiformis**)
Mesenteriolum processus vermiformis (**mesenteriolum appendicis vermiformis**)
Musculi intercostales intimi (innermost intercostal muscles)
Musculi interossei palmares (**musculi interossei volaris**)
Musculi interossei volaris (**musculi interossei palmares**)
Musculi interspinales dorsii (**musculi interspinales thoracis**)
Musculi rotatores dorsii (**musculi rotatores thoracis**)
Musculus caninus (**musculus levator anguli oris**)
Musculus compressor naris (**musculus nasalis, pars transversa**)
Musculus corrugator (**musculus corrugator supercilii**)
Musculus depressor labii inferioris (**musculus quadratus labii inferioris**)
Musculus dilatator naris (**musculus nasalis, pars alaris**)
Musculus erector spinæ (**musculus sacrospinalis**)
Musculus flexor digitorum sublimis (**musculus flexor digitorum superficialis**)

Musculus frontalis (**venter frontalis**)
Musculus glossopalatinus (**musculus palatoglossus**)
Musculus iliocostalis dorsii (**musculus iliocostalis thoracis**)
Musculus iliocostalis thoracis (**musculus iliocostalis dorsii**)
Musculus levator anguli oris (**musculus caninus**)
Musculus levator labii superioris (**caput infraorbitale m. quadrati labii superioris**)
Musculus levator labii superioris alaeque nasi (**caput angulare m. quadrati labii superioris**)
Musculus longissimus dorsii (**musculus longissimus thoracis**)
Musculus longissimus thoracis (**musculus longissimus dorsii**)
Musculus nasalis, pars alaris (**musculus dilatator naris**)
Musculus nasalis, pars transversa (**musculus compressor naris**)
Musculus occipitalis (**venter occipitalis**)
Musculus palatoglossus (**musculus glossopalatinus**)
Musculus palatopharyngeus (**musculus pharyngopalatinus**)
Musculus pharyngopalatinus (**musculus palatopharyngeus**)
Musculus quadratus labii inferioris (**musculus depressor labii inferioris**)
Musculus sacrospinalis (**musculus erector spinæ**)
Musculus semispinalis dorsii (**musculus semispinalis thoracis**)
Musculus semispinalis thoracis (**musculus semispinalis dorsii**)
Musculus sphincter vesicae (anulus urethrales, thickened portion of middle muscular coat of bladder)
Musculus spinalis dorsii (**musculus spinalis thoracis**)
Musculus spinalis thoracis (**musculus spinalis dorsii**)

- Musculus temporo-parietalis* (temporo-parietal division of epicranium muscle)
- Musculus transverso-spinalis* (any of many small muscles from transverse process to vertebral spines, including semispinalis, multifidus, and rotatores)
- Musculus triangularis* (musculus depressor anguli oris)
- Musculus zygomaticus* (musculus zygomaticus major)
- Musculus zygomaticus major* (musculus zygomaticus)
- Musculus zygomaticus minor* (caput zygomaticum m. quadrati labii superioris)
- Nervi digitales palmares communes* (nervi digitales volares communes)
- Nervi digitales volares communes* (nervi digitales palmares communes)
- Nervi pterygopalatini* (nervi sphenopalatini)
- Nervi sphenopalatini* (nervi pterygopalatini)
- Nervus laryngeus inferior* (rami pharyngei et laryngei, nervi vagi)
- Nervus lumboinguinalis* (ramus femoralis nervi genitofemoralis)
- Nervus meningeus, medius* (ramus meningeus, medius, nervi maxillaris)
- Nervus spermaticus externus* (ramus genitalis, nervi genitofemoralis)
- Nervus stato-acusticus* (cranial VIII nerve, with vestibular and cochlear branches and functions)
- Neuro-epithelium* (type of epithelium for nerve impulses, including that of rods and cones of retina and the hair cells of auris interna)
- Nodi lymphatici bronchopulmonales* (lymphoglandulae bronchiales)
- Nodi lymphatici colici medii* (lymphoglandulae mesocolicae)
- Nodi lymphatici gastrici dextrae* (lymphoglandulae gastricae inferiores)
- Nodi lymphatici gastrici sinistri* (lymphoglandulae gastricae superiores)
- Nodi lymphatici iliaci interni* (lymphoglandulae hypogastricae)
- Nodi lymphatici inguinales profundi* (lymphoglandulae subinguinales superficiales)
- Nodi lymphatici mandibulares* (lymph nodes of lower jaw)
- Nodi lymphatici mediastinales anteriores* (lymphoglandulae mediastinales anteriores)
- Nodi lymphatici retro-auriculares* (lymphoglandulae auriculares posteriores)
- Nodi lymphatici sternales* (lymphoglandulae sternales)
- Nodi lymphatici submentales* (lymph nodes in neck, beneath chin)
- Nucha* (used for back of the neck)
- Nucleus amygdalae* (corpus amygdaloideum)
- Nucleus centralis thalami* (central nucleus of the thalamus)
- Operculum fronto-parietale* (pars parietalis operculi)
- Operculum temporale* (pars temporalis operculi)
- Orificium externum uteri* (ostium uteri)
- Os cuneiforme primum* (os cuneiforme mediale)
- Os cuneiforme secundum* (os cuneiforme intermedium)
- Os cuneiforme tertium* (os cuneiforme laterale)
- Os multangulum majus* (os trapezium)
- Os multangulum minus* (os trapezoidum)
- Os naviculare manus* (os scaphoideum)
- Os naviculare pedis* (os naviculare)

Os sacrum anterior (os sacrum dorsalis)
Os sacrum posterior (os sacrum pelvina)
Os scaphoideum (os naviculare manus)
Os trapezium (os multangulum majus)
Os trapezoidum (os multangulum minus)
Ostium aortae (ostium arteriosum)
Ostium arteriosum (ostium aortae)
Ostium arteriosum (ostium trunci pulmonaris)
Ostium atrioventricularis dextrum (ostium venosum)
Ostium atrioventricularis sinistrum (ostium venosum)
Ostium uteri (orificium externum uteri)
Ostium venosum (ostium atrioventricularis dextrum)
Ostium venosum (ostium atrioventricularis sinistrum)
Palma manus (vola manus)
Papilla parotidea (small papilla at orifice of parotid duct of cheek)
Parametrium (connective tissue between layers of broad ligament along sides of uterus)
Pars analis recti (canalis analis)
Pars cavernosa, urethrae (pars spongiosa, urethrae)
Pars frontalis capsulae internae (crus anterius capsulae internae)
Pars intermedia (small subdivision of anterior lobe of hypophysis, extending to portion of posterior lobe)
Pars media lobuli parietalis inferioris (gyrus angularis)
Pars mobilis septi nasi (septum mobile nasi)
Pars occipitalis capsulae internae (crus posterius capsulae internae)
Pars parietalis operculi (operculum fronto-parietale)

Pars spongiosa, urethrae (pars cavernosa, urethrae)
Pars temporalis operculi (operculum temporale)
Pars tuberalis (small subdivision of anterior lobe of hypophysis, extending around infundibulum)
Pedunculus cerebellaris inferior (corpus restiforme)
Pedunculus cerebellaris medius (branchium pontis)
Pedunculus cerebellaris superior (brachium conjunctivum)
Periodontium (periosteum alveolare)
Periosteum alveolare (periodontium)
Pes hippocampi (digitationes hippocampi)
Phalanx primum, ossa dig. manus (phalanx proximalis)
Phalanx secunda (phalanx media)
Phalanx tertia (phalanx distalis)
Plexus pudendalis (plexus venosus epigastricae)
Plexus venosus epigastricae (plexus pudendalis)
Plica rectovesicalis (plica sacro-genitalis)
Plica sacro-genitalis (plica rectovesicalis)
Plica synovialis infrapatellaris (plica synovialis patellaris)
Plica synovialis patellaris (plica synovialis infrapatellaris)
Processus vermiformis (appendix vermiformis)
Radiatio occipitothalamica (radiatio optica)
Radiatio optica (radiatio occipitothalamica)
Radix longa ganglii ciliaris (ramus communicans cum ganglio ciliare)
Radix medialis, tractus olfactorii (stria medialis)
Rami laryngopharyngei ganglii submaxillaris (rami pharyngei ganglii submandibularis)

- Rami nasales anteriores, nervi ethmoidalis anterioris** (rami nasales interni, nervi ethmoidales anteriores)
- Rami nasales interni, nervi ethmoidales anterioris** (rami nasales anteriores, nervi ethmoidalis anteriores)
- Rami pharyngei et laryngei, nervi vagi** (*nervus laryngeus inferior*)
- Rami pharyngei ganglii submandibularis** (rami laryngopharyngei ganglii submaxillaris)
- Rami submandibularis, ganglii submandibularis** (rami submaxillares, ganglii submaxillaris)
- Rami submaxillares, ganglii submaxillaris** (rami submandibularis, ganglii submandibularis)
- Ramus anastomoticus** (ramus communicans)
- Ramus communicans** (*ramus anastomoticus*)
- Ramus communicans cum ganglio ciliare** (*radix longa ganglii ciliaris*)
- Ramus descendens** (ramus interventricularis sinistra)
- Ramus dexter a. pulmonalis** (arteria pulmonalis dextra)
- Ramus femoralis nervi genitofemoralis** (*nervus lumboinguinalis*)
- Ramus genitalis, nervi genitofemoralis** (*nervus spermaticus externus*)
- Ramus lateralis n. supraorbitalis** (lateral branch of supraorbital nerve, a continuation of the frontal branch of the ophthalmic nerve)
- Ramus medialis n. supraorbitalis** (medial branch of supraorbital nerve, a continuation of the frontal branch of the ophthalmic nerve)
- Ramus meningeus, medius, nervi maxillaris** (*nervus meningeus, medius*)
- Ramus sinister a. pulmonalis** (arteria pulmonalis sinistra)
- Recessus costodiaphragmaticus** (*sinus phrenicocostalis*)
- Recessus costomediastinalis** (*sinus costomediastinalis*)
- Recessus duodenalis superior** (*recessus duodenojejunalis*)
- Recessus duodenojejunalis** (*recessus duodenalis superior*)
- Recessus lateralis fossae rhomboideae** (*recessus lateralis ventriculi quarti*)
- Recessus lateralis ventriculi quarti** (*recessus lateralis fossae rhomboideae*)
- Recessus paracolici** (sulci paracolici)
- Recessus pleurae** (*sinus pleurae*)
- Regio hypogastricus** (regio publica)
- Regio iliakis** (regio inguinalis)
- Regio lumbaris** (regio lateralis)
- Rete foraminis ovalis** (venae emissariae foraminis ovalis)
- Retinaculum musculorum extensorum** (*ligamentum carpi dorsale*)
- Retinaculum musculorum extensorum inferius** (*ligamentum cruciatum cruris*)
- Retinaculum musculorum extensorum superius** (*ligamentum transversum cruris*)
- Retinaculum musculorum flexorum** (*ligamentum carpi transversum*)
- Retinaculum musculorum flexorum** (*ligamentum laciniatum*)
- Sacculi alveolares** (air sacs of alveolar ducts of respiratory bronchioles)
- Sacculus laryngis** (*appendix ventriculi laryngis*)
- Scapha** (fossa scaphoidea)
- Semen** (*sperma*).
- Septum lucidum** (*septum pellucidum*)
- Septum mediastinale** (mediastinum)
- Septum mobile nasi** (pars mobilis septi nasi)
- Septum pellucidum** (*septum lucidum*)
- Sinus anales** (*sinus rectales*)

- Sinus caroticus* (small dilatation at terminal part of common carotid artery)
- Sinus costomediastinalis* (recessus costomediastinalis)
- Sinus ethmoidales* (*cellulae ethmoidales*)
- Sinus obliquus paricardii* (pericardial sinus extending upward behind left atrium)
- Sinus phrenicocostalis* (recessus costodiaphragmaticus)
- Sinus pleurae* (recessus pleurae)
- Sinus rectales* (sinus anales)
- Sinus sigmoideus* (S-shaped sinus from sinus transversus down to a junction with internal jugular vein)
- Spatia anguli iridocornealis* (*spatia iridis*)
- Spatia iridis* (*spatia anguli iridocornealis*)
- Spatium perinei profundum* (space between superior and inferior fascia of urogenital diaphragm)
- Spatium perinei superficiale* (space between membrana perinei and membranes of fascia perinei superficialis, containing radix penis)
- Spatium retropubicum* (space between inferior aspect of apex vesicae and superior aspect of pubic symphysis and the two pubic bones)
- Sperma* (semen)
- Stratum griseum centrale* (*substantia grisea centralis*)
- Stria medialis* (*radix medialis, tractus olfactorii*)
- Substantia adamantina* (enamelum)
- Substantia eburnea* (dentinum)
- Substantia grisea centralis* (*stratum griseum centrale*)
- Substantia medullaris* (medulla)
- Substantia ossea* (cementum)
- Sulci paracolici* (*recessus paracolici*)
- Sulcus calcarinus* (*fissura calcarina*)
- Sulcus collateralis* (*fissura collateralis*)
- Sulcus hippocampi* (*fissura hippocampi*)
- Sulcus horizontalis cerebelli* (*fissura horizontalis cerebelli*)
- Sulcus intraventricularis, cordis* (*sulcus longitudinalis, cordis*)
- Sulcus lateralis* (*fissura cerebri lateralis*)
- Sulcus longitudinalis, cordis* (*sulcus intraventricularis, cordis*)
- Sulcus olfactorius* (narrow groove ascending from atrium between agger nasi and roof of cavum nasi)
- Sulcus parieto-occipitalis* (*fissura parietooccipitalis*)
- Sulcus venae cavae, hepatis* (*fossa venae cavae, hepatis*)
- Synarthroses* (*juncturae fibrosae*)
- Tectum, mesencephali* (*lamina quadrigemina*)
- Tendo crico-oesophageus* (tendon of muscular coat of esophagus)
- Tonsilla nasopharyngea* (lymphoid tissue at opening of auditory tube)
- Torus levatorius* (mucous membrane covering levator veli palatini muscles in lateral wall of nasal portion of pharynx)
- Trabecula septomarginalis* (band of fibers at lower apex of right ventricle, connecting septum to base of anterior papillary muscle)
- Tractus olivocerebellaris* (*fibrae cerebello-olivares*)
- Trigonum nervi vagi* (*ala cinerea*)
- Trochlea phalangis* (*caput phalangis*)
- Truncus coeliacus* (*arteria coeliaca*)
- Tuberculum conoideum et linea trapezoidea* (*tuberositas coracoides*)
- Tuberculum gracile* (*clava*)
- Tuberculum labii superioris* (slightly elevated lower portion of philtrum)
- Tuberculum laterale* (tubercle on posterior process of talus)

- Tuberculum mediale* (tubercle on posterior process of talus)
- Tuberositas coracoidea* (tuberculum conoideum et linea trapezoidea)
- Tuberositas costalis* (impressio ligamenti costoclavicularis)
- Tuberositas phalangis distalis* (*tuberositas unguicularis*)
- Tuberositas unguicularis* (tuberositas phalangis distalis)
- Tubus digestorius* (canalis alimentarius)
- Tunica adventitia, tubae uterinae* (tunica subserosa tubae uterinae)
- Tunica mucosa (lamina mucosa)*
- Tunica mucosa tympani* (membrana tympani)
- Tunica subserosa tubae uterinae* (*tunica adventitia, tubae uterinae*)
- Tunica vaginalis communis* (fascia spermatica interna)
- Vaginae mucosae* (vaginae synoviales)
- Vaginae synoviales* (*vaginae mucosae*)
- Valvula coli* (valvula iliecolica)
- Valvula iliecolica* (*valvula coli*)
- Vena anonyma* (vena brachiocephalica)
- Vena auditiva interna* (vena labyrinthi)
- Vena brachiocephalica* (*vena anonyma*)
- Vena diploica frontalis* (*vena diploica temporalis*)
- Vena diploica temporalis* (vena diploica frontalis)
- Vena facialis posterior* (vena retromandibularis)
- Vena frontalis* (vena supratrochlearis)
- Vena haemorrhoidalis* (vena rectalis)
- Vena hypogastrica* (vena iliaca interna)
- Vena iliaca interna* (*vena hypogastrica*)
- Vena labyrinthi* (*vena auditiva interna*)
- Vena prepylorica* (a branch of the portal vein, extending across anterior surface of pylorus)
- Vena rectalis* (*vena haemorrhoidalis*)
- Vena retromandibularis* (*vena facialis posterior*)
- Vena scapularis transversa* (vena suprascapularis)
- Vena subcostalis* (subcostal vein: the right subcostal vein is received by the azygos vein, the left subcostal by the hemiazygos vein)
- Vena suprascapularis* (*vena scapularis transversa*)
- Vena supratrochlearis* (*vena frontalis*)
- Vena terminalis* (vena thalamostriata)
- Vena thalamostriata* (*vena terminalis*)
- Vena vertebralis anterior* (small vein from plexus around transverse process of upper cervical vertebrae, ending in lower portion of vertebral vein)
- Venae emissariae* (*emissarium*)
- Venae emissariae foraminis ovalis* (*rete foraminis ovalis*)
- Venae intestinales* (venae jejunaes et ileae)
- Venae jejunaes et ileae* (*venae intestinales*)
- Venter frontalis* (*musculus frontalis*)
- Venter occipitalis* (*musculus occipitalis*)
- Vertex vesicae* (apex vesicae)
- Vola manus* (palma manus)
- Zona haemorrhoidalis* (the portion of anal canal containing plexus venosus rectalis)

APPENDIX B

TABLE OF METRIC SYSTEM WITH CONVERSION TABLES

METRIC SYSTEM

| Scale | Table | | Grams | | Grains |
|------------|-------------|---|--------|---|-----------|
| Myria..... | 1 Myriagram | = | 10,000 | = | 154,323.5 |
| Kilo..... | 1 Kilogram | = | 1,000. | = | 15,432.35 |
| Hecto..... | 1 Hectogram | = | 100. | = | 1,543.23 |
| Deca..... | 1 Decagram | = | 10. | = | 154.323 |
| Unit..... | 1 Gram | = | 1. | = | 15.432 |
| Deci..... | 1 Decigram | = | .1 | = | 1.5432 |
| Centi..... | 1 Centigram | = | .01 | = | .15432 |
| Milli..... | 1 Milligram | = | .001 | = | .01543 |

The Arabic numerals are used with the symbol after the quantity, as 10 Gm., or 3 ml., etc. Portions of a measure are always expressed decimally. Grams should always be abbreviated with a capital initial, as Gm. A drop (gtt) of water is sometimes considered equivalent to a minim (m) but should not be used without physician's instructions.

CONVERSION TABLES (for Measures Most Commonly Used in the United States)

| Lengths | Cm. | Inches | Feet | Yards | Meters |
|-------------------|---------|--------|--------|---------|--------|
| 1 centimeter..... | 1.000 | 0.394 | 0.0328 | 0.01094 | 0.0100 |
| 1 inch..... | 2.54 | 1.000 | 0.0833 | 0.0278 | 0.0254 |
| 1 foot..... | 30.48 | 12.00 | 1.000 | 0.333 | 0.305 |
| 1 yard..... | 91.4 | 36.00 | 3.000 | 1.000 | 0.914 |
| 1 meter..... | 100.0 | 39.4 | 3.28 | 1.094 | 1.000 |
| 1 kilometer..... | 100000. | 39400. | 3280. | 1094. | 1000. |
| 1 mile..... | 160903. | 63360. | 5280. | 1760. | 1609. |

| Volumes | Cc. | Fl. drams | Cu. In. | Fl. Oz. | Quarts | Liters |
|-------------------------|-------|-----------|---------|---------|----------|----------|
| 1 cubic centimeter..... | 1.000 | 0.270 | 0.0610 | 0.0338 | 0.001057 | 0.001000 |
| 1 fluid dram..... | 3.70 | 1.000 | 0.226 | 0.1250 | 0.00391 | 0.00370 |
| 1 cubic inch..... | 16.39 | 4.43 | 1.000 | 0.554 | 0.0173 | 0.01639 |
| 1 fluid ounce..... | 29.6 | 8.00 | 1.804 | 1.000 | 0.03125 | 0.0296 |
| 1 quart..... | 946. | 255. | 57.75 | 32.0 | 1.000 | 0.946 |
| 1 liter..... | 1000. | 270. | 61.0 | 33.8 | 1.056 | 1.000 |

| Weights | Gr. | Gm. | Ap. Oz. | Lb. | Kilos |
|--------------------------|--------|--------|---------|-----------|-----------|
| 1 grain (gr.)..... | 1.000 | 0.0648 | 0.00208 | 0.0001429 | 0.0000648 |
| 1 gram (Gm.)..... | 15.43 | 1.000 | 0.03215 | 0.002205 | 0.001000 |
| 1 apothecary ounce..... | 480. | 31.1 | 1.000 | 0.06855 | 0.0311 |
| 1 avoirdupois pound..... | 7000. | 454. | 14.58 | 1.000 | 0.454 |
| 1 kilogram..... | 15432. | 1000. | 32.15 | 2.205 | 1.000 |

• RULES FOR CONVERTING ONE SYSTEM TO ANOTHER

To Convert Grains, Drams, and Ounces into Grams or CC.:

Divide the number of grains by 15.
Multiply the number of drams by 4.
Multiply the number of ounces by 30.
The result = the number of grams or cc.

To Convert from the Metric System

Milligrams to grains: Multiply by 0.0154.
Grams to grains: Multiply by 15.
Grams to drams: Multiply by 0.257.
Grams to ounces: Multiply by 0.0311.

To Convert into Metric Fluid Measures

Minims to cubic millimeters: Multiply by 63.
Minims to cubic centimeters: Multiply by 0.06.

To Convert Metric Fluid Measures

Cubic millimeters to minims: Divide by 63 (or multiply by 0.016).
Cubic centimeters to minims: Multiply by 16.
Cubic centimeters to fluid ounces: Divide by 30 (or multiply by 0.033).
Liters to pints (U.S.): Multiply by 2.1.
Liters to pints (Imperial): Multiply by 1.76.

To Convert Centigrade Degrees to Fahrenheit Degrees

Multiply the number of centigrade degrees by 9/5 and add 32 to the result.
Example: 55°C. $\times 9/5 = 99 + 32 = 131^\circ \text{F.}$

To convert Fahrenheit degrees to centigrade degrees: Subtract 32 from the number of centigrade degrees and multiply the difference by 5/9.
Example: 243° F. $- 32 = 211 \times 5/9 = 117.2^\circ$

UNITS OF LENGTH

| <i>Millimeters</i> | <i>Centimeters</i> | <i>Inches</i> | <i>Feet</i> | <i>Yards</i> | <i>Meters</i> |
|--------------------|--------------------|---------------|-------------|--------------|---------------|
| 1 mm. = 1.00 | 0.100 | 0.0394 | 0.00328 | 0.0011 | 0.0010 |
| 1 cm. = 10.0 | 1.00 | 0.394 | 0.0328 | 0.0109 | 0.0100 |
| 1 in. = 25.4 | 2.54 | 1.00 | 0.0833 | 0.0278 | 0.0254 |
| 1 ft. = 304.8 | 30.48 | 12.00 | 1.00 | 0.333 | 0.305 |
| 1 yd. = 914. | 91.4 | 36.0 | 3.00 | 1.000 | 0.914 |
| 1 m. = 1000. | 100. | 39.4 | 3.28 | 1.094 | 1.00 |

1 μ = 1 mu = 1 micron = 0.001 millimeter. One mm. = 1000 μ .

1 km. = 1 kilometer = 1000 meters = 0.6215 mile.

1 mile = 5280 feet = 1.609 kilometers.

UNITS OF VOLUME

| <i>Cubic Centimeters</i> | <i>Fluid Drams</i> | <i>Cubic Inches</i> | <i>Fluid Ounces</i> | <i>Quarts</i> | <i>Liters</i> |
|--------------------------|--------------------|---------------------|---------------------|---------------|---------------|
| 1 cc. = 1.00 | 0.270 | 0.0610 | 0.0338 | 0.00106 | 0.00100 |
| 1 fl. Z = 3.70 | 1.000 | 0.226 | 0.1250 | 0.00391 | 0.00370 |
| 1 cu. in. = 16.39 | 4.43 | 1.000 | 0.554 | 0.0173 | 0.01639 |
| 1 fl. S = 29.6 | 8.00 | 1.804 | 1.000 | 0.03125 | 0.0296 |
| 1 qt. = 946. | 255. | 57.75 | 32.00 | 1.000 | 0.946 |
| 1 L. = 1000. | 270. | 61.0 | 33.8 | 1.056 | 1.000 |

1 cubic millimeter = 0.001 cubic centimeter; 1 cc. = 1000 cu. mm.

1 gallon = 4 quarts = 8 pints = 3.78 liters.

1 pint = 473 cc.

UNITS OF WEIGHT

| <i>Grains</i> | <i>Grams</i> | <i>Apothecary Ounces</i> | <i>Pounds Avoirdupois</i> | <i>Kilograms</i> |
|---------------------|--------------|--------------------------|---------------------------|------------------|
| 1 gr. = 1.000 | 0.0648 | 0.00208 | 0.0001429 | 0.000065 |
| 1 Gm. = 15.43 | 1.000 | 0.03215 | 0.002205 | 0.001000 |
| 1 S = 480. | 31.1 | 1.000 | 0.06855 | 0.0311 |
| 1 lb. = 7000. | 454. | 14.58. | 1.000 | 0.454 |
| 1 Kg. = 15432. | 1000. | 32.15 | 2.205 | 1.000 |

1 γ = 1 gamma = 1 microgram = 0.001 milligram; 1000 γ = 1 mg.

1 mg. = 1 milligram = 0.001 Gm.; 1000 mg. = 1 Gm.

1 grain = 64.8 mg.; 1 mg. = 0.0154 grain.

SOURCE: *Taber's Cyclopedic Medical Dictionary*, Davis, 1957.

APPENDIX C

PREFIXES AND SUFFIXES

| | |
|---|---|
| a- , an- . Negative. | homo , homeo- . Same; similar. |
| a- , ab- , abs- . Away from. | hydra , hydro- . Relating to water. |
| ad- , -ad . Toward. | hyp , hyph , hypo- . Under. |
| -aemia . Blood. | hyper- . Over; above; beyond. |
| aer- . Air. | hypo- . Under. |
| -aesthesia . Sensation. | -iasis . Condition; pathological state. |
| -algnesia , algia . Suffering; pain. | idio- . Peculiar to the individual or organ. |
| algi- . Pain. | ileo- . Relating to the ileum. |
| all- . Other. | in- . In; into; not. |
| amb- . Both; on both sides. | infra- . Beneath. |
| amph- . Around; on both sides. | inter- . Between. |
| ana- , an- . Up. | intra , intro- . Within. |
| angio- . Relating to blood or lymph vessels. | -ism . Condition; theory. |
| ante- . Before. | iso- . Equal. |
| anti- . Against. | -itis . Inflammation. |
| apo- . From; opposed. | -ize . To treat by special method. |
| -ase . Enzyme. | juxta- . Near. |
| aut- , auto- . Self. | karyo- . Nucleus; nut. |
| bi , bis- . Twice; double. | kata- , kath- . Down. |
| brachy- . Short. | kera- . Horn; indicates hardness. |
| brady- . Slow. | kinesi- . Movement. |
| cac- , caco- . Bad; evil. | -kinesis . Motion. |
| cat , cata , cath- . Down. | lact- . Milk. |
| -cele . A tumor; a cyst; a hernia. | laparo- . The loin; relating to the loin or abdomen. |
| cent- . Hundred. | laryng , laryngo- . The larynx. |
| cephal- . Relating to a head. | latero- . Side. |
| chrom- , chromo- . Color. | lepto- . Small; soft. |
| -cide . Causing death. | leuco , leuko- . White. |
| circum- . Around. | -lite , -lith . A stone; a calculus. |
| co , com , con- . Together. | lith- . A stone. |
| contra- . Against. | -logia , -logy . Science of; study of. |
| cyst- , -cyst . Bag; bladder. | -lysis . Setting free; disintegration. |
| -cyte . A cell. | macro- . Large; long; big. |
| dacry- . Tears. | mal- . Bad; poor; evil. |
| dactyl- . Fingers. | med- , medi- . Middle. |
| de- . From; not. | mega , megal- . Large; great. |
| deca- . Ten. | -megalia or megaly . Large; great; extreme. |
| deci- . Tenth. | melan- , melano- . Black. |
| semi- . Half. | mes- , meso- . Middle. |
| dent- . Relating to the teeth. | meta- . Beyond; over; between; change, or transposition. |
| derma- . The skin. | -meter . Measure. |
| di- . Double; apart from. | metra , metro- . The uterus. |
| dia- . Through; between; asunder. | micro- . Small. |
| diplo , diplo- . Double. | mio- . Less; smaller. |
| dis- . Negative; double; apart; absence of. | mono- . Single. |
| -dynia . Pain. | multi- . Many. |
| dys- . Difficult; bad. | my , myo- . Muscle. |
| ec , ecto- . Out; on the outside. | myel , myelo- . Marrow. |
| -ectomy . A cutting out. | myxa , myxo- . Mucus. |
| ef , es , ex , exo- . Out | neo- . New. |
| -emesis . Vomiting. | neph , nephra , nephro- . Kidney. |
| -emia . Blood. | neu , neuro- . Nerve. |
| en- . In, into. | niter , nitro- . Nitrogen. |
| endo- . Within. | non- , not- . No. |
| entero- . Relating to the intestine. | nucleo- . A nucleus. |
| ento- . Within. | ob- . Against. |
| epi- . Upon. | oculo- . The eye. |
| -esthesia . Sensation. | -ode , oid . Form; shape; resemblance. |
| eu- . Well. | odont- . A tooth. |
| ex- ; exo- . Out. | -oid . Form; shape; resemblance. |
| extra- . On the outside; beyond. | oligo- . Few. |
| fore- . Before; in front of. | -oma . A tumor. |
| -form . Form. | omo- . Shoulder. |
| -fuge . To drive away. | o- . An egg; ovum. |
| galact , galacto- . Milk. | oophoron- . Ovary. |
| gaster , gastro- . The stomach; the belly. | opisth- . Backward. |
| -gene , -genesis , -genetic , -genic . Production; origin; formation. | orchid- . Testicle. |
| glosso- . Relating to the tongue. | ortho- . Straight; normal. |
| -gog , gogue . To make flow. | os- . A mouth; a bone. |
| -gram . A tracing; a mark. | -osis . Condition; disease; intensive. |
| -graphy . A writing; a record. | oste , osteo- . A bone. |
| hem , hemato- . Relating to the blood. | -ostomosis , ostomy . To furnish with a mouth or an outlet. |
| hemi- . Half. | -otomy . Cutting. |
| hepa- , hepar- , hepato- . Liver. | oxy- . Sharp; acid. |
| hetero- . Other; indicating dissimilarity. | |
| holo- . All. | |

- pachy-**. Thick.
pan-. All; entire.
para-. Alongside of.
path-, -path, -pathy. Disease; suffering.
-penia. Lack.
per-. Excessive; through.
peri-. Around.
-phobia. Fear.
-phylaxis. Protection.
-plasm. To mold.
-plastic. Molded; indicates restoration of lost or badly formed features.
-plegia. A stroke.
plur. More.
pne-. Relating to the air or lungs.
poly-. Much; many.
post-. After.
pre-. Before.
pro-. Before; in behalf of.
proto-. First.
pseud, pseudo-. False.
psych-. The soul; the mind.
py-, pyo-. Pus.
re-. Back; again.
retro-. Backward.
-rhage, -rhagia. Hemorrhage; flow.
-rhapfy. A suturing or stitching.
-rhea. To flow; indicates discharge.
sacchar-. Sugar.
sacro-. Sacrum.
salping, salpingo-. A tube; relating to a fallopian tube.
sarco-. Flesh.
sclero-. Hard; relating to the sclera.
-sclerosis. Dryness; hardness.
-scopy. To see.
semi-. Half.
-stomosis, stormy. To furnish with a mouth or outlet.
sub-. Under.
super, supra-. Above.
syn-. With; together.
tele. Distant; far.
tetra-. Four.
thio-. Sulfur.
thyro-. Thyroid gland.
-tomy. Cutting.
trans-. Across.
tri-. Three.
tropho-. Relating to nutrition.
-trophic. Relating to nourishment.
uni-. One.
-uria. Relating to the urine.
urino, uro-. Relating to the urine or urinary organs.
vaso-. A vessel.
venter, ventro-. The abdomen.
xanth-. Yellow.

SOURCE: *Taber's Cyclopedic Medical Dictionary*, Davis, 1957.

APPENDIX D

CHEMICAL ELEMENTS, SYMBOL, VALENCE, AND ATOMIC WEIGHT

| <i>Element</i> | <i>Symbol</i> | <i>Valence</i> | <i>Atomic Number</i> | <i>Atomic Weight</i> | <i>Specific Gravity or Density</i> | <i>Melting Point °C</i> | <i>Boiling Point °C</i> |
|--------------------|---------------|----------------|--------------------------|--------------------------|--|-----------------------------|-----------------------------|
| Actinium..... | Ac | 3 | 89 | 227 | | | |
| Aluminum..... | Al | 3 | 13 | 26.97 | 2.70 | 658.7 | 1800.0 |
| Americium..... | Am | | 95 | 241 | | | |
| Antimony..... | Sb | 3, 5 | 51 | 121.76 | 6.68 | 630.0 | 1635.0±8° |
| Argon..... | A | 0 | 18 | 39.944 | 1.782 | -189.2 | -185.7 |
| Arsenic..... | As | 3, 5 | 33 | 74.91 | 5.73 | 500.0* | 615.0 |
| Astatine..... | At | 1, 3, 5, 7 | 85 | 210 | | | |
| Barium..... | Ba | 2 | 56 | 137.36 | 3.5 | 850.0 | 1140.0 |
| Berkelium..... | Bk | | 97 | 243(?) | | | |
| Beryllium..... | Be, Gl | 2 | 4 | 9.02 | 1.85 | 1350.0 | 1530.0 |
| Bismuth..... | Bi | 3, 5 | 83 | 209.00 | 9.78 | 271.0 | 1450.0 |
| Boron..... | B | 3 | 5 | 10.82 | 2.5 | 2000.0 | 2550.0* |
| Bromine..... | Br | 1, 3, 5, 7 | 35 | 79.916 | 3.12 | -7.2 | 58.8 |
| Cadmium..... | Cd | 2 | 48 | 112.41 | 8.65 | 320.9 | 778.0 |
| Calcium..... | Ca | 2 | 20 | 40.08 | 1.54 | 810.0 | 1439.0±5° |
| Californium..... | Cf | | 98 | 244(?) | | | |
| Carbon..... | C | 2, 3, 4 | 6 | 12.01 | 1.88-3.5 | 3500.0* | 4200.0 |
| Cerium..... | Ce | 3, 4 | 58 | 140.13 | 6.90 | 640.0 | 1400.0 |
| Cesium..... | Cs | 1 | 55 | 132.91 | 1.87 | 28.5 | 670.0 |
| Chlorine..... | Cl | 1, 3, 5, 7 | 17 | 35.457 | 1.56 | -101.6 | -34.6 |
| Chromium..... | Cr | 2, 3, 6 | 24 | 52.01 | 7.1 | 1615.0 | 2200.0 |
| Cobalt..... | Co | 2, 3 | 27 | 58.94 | 8.9 | 1480.0 | 2900.0 |
| Columbium..... | Cb, Nb | 3, 5 | 41 | 92.91 | 8.4 | 1950.0 | 3300.0 |
| Copper..... | Cu | 1, 2 | 29 | 63.57 | 8.93-8.95 | 1083.0 | 2310.0 |
| Curium..... | Cm | 3 | 96 | 242 | | | |
| Dysprosium..... | Dy | 3 | 66 | 162.46 | | | |
| Erbium..... | Er | 3 | 68 | 167.2 | 4.77(?) | | |
| Europium..... | Eu | 2, 3 | 63 | 152.0 | | 1100-1200 | |
| Fluorine..... | F | 1 | 9 | 19.00 | 1.11 | -223.0 | -187.0 |
| Francium..... | Fa | | 87 | 224 | | | |
| Gadolinium..... | Gd | 3 | 64 | 156.9 | | | |
| Gallium..... | Ga | 2, 3 | 31 | 69.72 | 5.91 | 29.75 | 2000±150° |
| Germanium..... | Ge | 4 | 32 | 72.60 | 5.36 | 958.0 | 2700 volatilizes |
| Gold..... | Au | 1, 3 | 79 | 197.2 | 19.32 | 1063.0 | 2600.0 |
| Hafnium..... | Hf | 4 | 72 | 178.6 | 13.3 | 2207.0 | 3200.0 |
| Helium..... | He | 0 | 2 | 4.003 | 0.177 | -272.2 | -268.9 |
| Holmium..... | Ho | 3 | 67 | 163.5 | | | |
| Hydrogen..... | H | 1 | 1 | 1.0081 | 0.07 | -259.0 | -252.8 |
| Illium..... | Il | 3(?) | 61 | 146.9 | | | |
| Indium..... | In | 3 | 49 | 114.76 | 7.28 | 155.0 | 1450.0 |
| Iodine..... | I | 1, 3, 5, 7 | 53 | 126.92 | 4.93 | 113.5 | 183.0 |
| Iridium..... | Ir | 3, 4 | 77 | 193.1 | 22.42 | 2440±15° C. | 4400.0 |
| Iron..... | Fe | 2, 3 | 26 | 55.84 | 7.865 | 1535.0 | 3000.0 |
| Krypton..... | Kr | 0 | 36 | 83.7 | 3.708 | -157.0 | -152.9 |
| Lanthanum..... | La | 3 | 57 | 138.92 | 6.15 | 885±5° C. | 1800.0 |
| Lead..... | Pb | 2, 4 | 82 | 207.21 | 11.35 | 327.5 | 1620.0 |
| Lithium..... | Li | 1 | 3 | 6.94 | 0.534 | 186.0 | 1336.0 |
| Lutecium..... | Lu | 3 | 71 | 175.0 | | | |
| Magnesium..... | Mg | 2 | 12 | 24.32 | 1.74 | 651.0 | 1110.0 |
| Manganese..... | Mn | 2, 3, 4, 6, 7 | 25 | 54.93 | 7.2 | 1260.0 | 1900.0 |
| Mercury..... | Hg | 1, 2 | 80 | 200.61 | 13.595 | -38.89 | 356.9 |
| Molybdenum..... | Mo | 3, 4, 6 | 42 | 95.95 | 10.2 | 2620.0 | 3700.0 |
| Neodymium..... | Nd | 3 | 60 | 144.27 | 6.95 | 840.0 | |
| Neon..... | Ne | 0 | 10 | 20.183 | 0.9002 | -248.67 | -245.9 |
| Neptunium..... | Np | 3, 4, 5, 6 | 93 | 237 | | | |
| Nickel..... | Ni | 2, 3 | 28 | 58.69 | 8.90 | 1452.0 | 2900.0 |
| Nitrogen..... | N | 3, 5 | 7 | 14.008 | 0.808 | -209.9 | -195.8 |
| Osmium..... | Os | 2, 3, 4, 8 | 76 | 190.2 | 22.48 | 2700.0 | 4450.0 |
| Oxygen..... | O | 2 | 8 | 16.00 | 1.14 | -218.4 | -183.0 |
| Palladium..... | Pd | 2, 4 | 46 | 106.7 | 11.40 | 1555.0 | 2200.0 |
| Phosphorus..... | P | 3, 5 | 15 | 31.02 | 1.82-2.20 | 44.1 | 280.0 |
| Platinum..... | Pt | 2, 4 | 78 | 195.23 | 21.45 | 1755.0 | 4050.0 |
| Plutonium..... | Pu | 3, 4, 6 | 94 | 239 | | | |
| Polonium..... | Po | | 84 | 210.0(?) | | | |
| Potassium..... | K | 1 | 19 | 39.096 | 0.86 | 62.3 | 760.0 |
| Praseodymium..... | Pr | 3 | 59 | 140.92 | 6.5 | 940.0 | |
| Protoactinium..... | Pa | | 91 | 231.0 | | | |
| Radium..... | Ra | 2 | 88 | 226.05 | 5.0 | 960.0 | 1140.0 |
| Radon..... | Rn | 0 | 86 | 222.0 | 9.73 | -71.0 | -61.8 |
| Rhenium..... | Re | | 75 | 186.31 | 20.53 | 3440.0 | |

*Element sublimes unless under pressure.

| <i>Element</i> | <i>Symbol</i> | <i>Valence</i> | <i>Atomic Number</i> | <i>Atomic Weight</i> | <i>Specific Gravity or Density</i> | <i>Melting Point °C</i> | <i>Boiling Point °C</i> |
|-----------------|---------------|----------------|--------------------------|--------------------------|--|-----------------------------|-----------------------------|
| Rhodium..... | Rh | 3 | 45 | 102.91 | 12.5 | 1985±15° C. | 2500.0 |
| Rubidium..... | Rb | 1 | 37 | 85.48 | 1.53 | 38.4 | 700.0 |
| Ruthenium..... | Ru | 3, 4, 6, 8 | 44 | 101.7 | 12.2 | 2450.0 | 4150.0 |
| Samarium..... | Sm | 3 | 62 | 150.43 | 7.7-7.8 | 1300-1400 | |
| Scandium..... | Sc | 3 | 21 | 45.10 | 2.5 (?) | 1200.0 | 2400.0 |
| Selenium..... | Se | 2, 4, 6 | 34 | 78.96 | 4.47-4.80 | 217.0 | 688.0 |
| Silicon..... | Si | 4 | 14 | 28.06 | 2.42 | 1420.0 | 2600.0 |
| Silver..... | Ag | 1 | 47 | 107.88 | 10.50 | 960.5 | 1950.0 |
| Sodium..... | Na | 1 | 11 | 22.997 | 0.971 | 97.5 | 880.0 |
| Strontium..... | Sr | 2 | 38 | 87.63 | 2.6 | 752.0 | 1150.0 |
| Sulfur..... | S | 2, 4, 6 | 16 | 32.06 | 1.957, 2.07 | 112.8, 119.0 | 444.6 |
| Tantalum..... | Ta | 5 | 73 | 180.88 | 16.6 | 2850.0 | 4100.0 |
| Technetium..... | Tc | | 43 | 99 | | | |
| Tellurium..... | Te | 2, 4, 6 | 52 | 127.61 | 6.24 | 452.0 | 1390.0 |
| Terbium..... | Tb | 3 | 65 | 159.2 | | | |
| Thallium..... | Tl | 1, 3 | 81 | 204.39 | 11.85 | 303.5 | 1650.0 |
| Thorium..... | Th | 4 | 90 | 232.12 | 11.2 | 1845.0 | 3000.0 |
| Thulium..... | Tm | 3 | 69 | 169.4 | | | |
| Tin..... | Sn | 2, 4 | 50 | 118.7 | 6.55 | 231.9 | 2270.0 |
| Titanium..... | Ti | 3, 4 | 22 | 47.90 | 4.5 | 1800.0 | 3000.0 |
| Tungsten..... | W | 6 | 74 | 183.92 | 19.3 | 3370.0 | 4727.0 |
| Uranium..... | U | 4, 6 | 92 | 238.07 | 18.68 | 1850.0 | |
| Vanadium..... | V | 3, 5 | 23 | 50.95 | 5.87 | 1715.0 | 3400.0 |
| Xenon..... | Xe | 0 | 54 | 131.3 | 3.06 | -112.0 | -107.1 |
| Ytterbium..... | Yb | 3 | 70 | 173.04 | | 1800.0 | |
| Yttrium..... | Y | 3 | 39 | 88.92 | 5.51 | 1490.0 | 2500.0 |
| Zinc..... | Zn | 2 | 30 | 65.35 | 7.14 | 419.4 | 907.0 |
| Zirconium..... | Zr | 4 | 40 | 91.22 | 6.4 | 1700.0 | 2900.0 |

Elements recently added to the periodic table include the following: Einsteinium (Es; No. 99; At. wt. 255); Fermium (Fm; No. 100; At. wt. 255); Mendelevium (Md; No. 101; At. wt. 256); and Nobelium (No; No. 102; At. wt. 253).

TERMINOLOGY CHANGES

Alabamine, *astatine*; argentum, *silver*; aurum, *gold*; cuprum, *copper*; cyclonium, *illinium*; ferrum, *iron*; florentium, *illinium*; glucinum, *beryllium*; hydrargyrum, *mercury*; kalium, *potassium*; masurium, *technetium*; natrium, *sodium*; niobium, *columbium*; niton, *radon*; plumbum, *lead*; promethium, *illinium*; stabium, *antimony*; stannum, *tin*; virginium, *francium*; wolfranium, *tungsten*; zincum, *zinc*.

SOURCE: *Taber's Cyclopedic Medical Dictionary*, Davis, 1957.

APPENDIX

FOOD AND NUTRITION BOARD, RECOMMENDED DAILY DIETARY

| | Age years | Weight kg. (lb.) | Height cm. (in.) | Calories | Protein gm. |
|------------------------|---------------------------|---------------------|---------------------|-------------------|----------------|
| Men | 25 | 70 (154) | 175 (69) | 3200 ³ | 70 |
| | 45 | 70 (154) | 175 (69) | 3000 | 70 |
| | 65 | 70 (154) | 175 (69) | 2550 | 70 |
| Women . . | 25 | 58 (128) | 163 (64) | 2300 | 58 |
| | 45 | 58 (128) | 163 (64) | 2200 | 58 |
| | 65 | 58 (128) | 163 (64) | 1800 | 58 |
| | Pregnant (second half) | | | +300 | +20 |
| | Lactating (850 ml. daily) | | | +1000 | +40 |
| Infants ⁴ . | 0-1/12 ⁴ | | | | See |
| | 2/12-6/12 6 (13) | | 60 (24) | kg. × 120 | Footnote |
| | 7/12-12/12 9 (20) | | 70 (28) | kg. × 100 | 4 |
| Children. | 1-3 | 12 (27) | 87 (34) | 1300 | 40 |
| | 4-6 | 18 (40) | 109 (43) | 1700 | 50 |
| | 7-9 | 27 (60) | 129 (51) | 2100 | 60 |
| | 10-12 | 36 (79) | 144 (57) | 2500 | 70 |
| Boys | 13-15 | 49 (108) | 163 (64) | 3100 | 85 |
| | 16-19 | 63 (139) | 175 (69) | 3600 | 100 |
| Girls | 13-15 | 49 (108) | 160 (63) | 2600 | 80 |
| | 16-19 | 54 (120) | 162 (64) | 2400 | 75 |

* SOURCE: Publication 589, National Academy of Sciences — National Research Council.

¹ The allowance levels are intended to cover individual variations among most normal persons as they live in the United States under usual environmental stresses. The recommended allowances can be attained with a variety of common foods, providing other nutrients for which human requirements have been less well defined. See text for more detailed discussion of allowances and of nutrients not tabulated.

² Niacin equivalents include dietary sources of preformed vitamin and the precursor, tryptophan. Sixty milligrams tryptophan equals 1 milligram niacin.

³ Calorie allowances apply to individuals usually engaged in moderate physical activity. For office workers or others in sedentary occupations they

E*

NATIONAL RESEARCH COUNCIL ALLOWANCES,¹ REVISED 1958

| Calcium gm. | Iron mg. | Vitamin A I.U. | Thiam. mg. | Ribo. mg. | Niacin ² mg. equiv. | Asc. Acid mg. | Vitamin D I.U. |
|----------------|-------------|----------------------|---------------|--------------|--------------------------------------|---------------------|----------------------|
| 0.8 | 10 | 5000 | 1.6 | 1.8 | 21 | 75 | |
| 0.8 | 10 | 5000 | 1.5 | 1.8 | 20 | 75 | |
| 0.8 | 10 | 5000 | 1.3 | 1.8 | 18 | 75 | |
| 0.8 | 12 | 5000 | 1.2 | 1.5 | 17 | 70 | |
| 0.8 | 12 | 5000 | 1.1 | 1.5 | 17 | 70 | |
| 0.8 | 12 | 5000 | 1.0 | 1.5 | 17 | 70 | |
| 1.5 | 15 | 6000 | 1.3 | 2.0 | +3 | 100 | 400 |
| 2.0 | 15 | 8000 | 1.7 | 2.5 | +2 | 150 | 400 |
| 0.6 | 5 | 1500 | 0.4 | 0.5 | 6 | 30 | 400 |
| 0.8 | 7 | 1500 | 0.5 | 0.8 | 7 | 30 | 400 |
| 1.0 | 7 | 2000 | 0.7 | 1.0 | 8 | 35 | 400 |
| 1.0 | 8 | 2500 | 0.9 | 1.3 | 11 | 50 | 400 |
| 1.0 | 10 | 3500 | 1.1 | 1.5 | 14 | 60 | 400 |
| 1.2 | 12 | 4500 | 1.3 | 1.8 | 17 | 75 | 400 |
| 1.4 | 15 | 5000 | 1.6 | 2.1 | 21 | 90 | 400 |
| 1.4 | 15 | 5000 | 1.8 | 2.5 | 25 | 100 | 400 |
| 1.3 | 15 | 5000 | 1.3 | 2.0 | 17 | 80 | 400 |
| 1.3 | 15 | 5000 | 1.2 | 1.9 | 16 | 80 | 400 |

are excessive. Adjustments must be made for variations in body size, age, physical activity, and environmental temperature.

⁴ The Board recognizes that human milk is the natural food for infants and feels that breast feeding is particularly desired procedure for meeting nutrient requirements in the first months of life. Breast feeding is particularly indicated during the first month when infants show handicaps in homeostasis due to different rates of maturation of digestive, excretory, and endocrine functions. Recommendations as listed pertain to nutrient intake as afforded by cow's milk formulas and supplementary foods given the infant when breast feeding is terminated. Allowances are not given for protein during infancy.

APPENDIX F THERMOMETRIC EQUIVALENTS AND COMPARATIVE THERMOMETRIC SCALE

Thermometric Equivalents

| C | F | C | F | C | F | C | F |
|----|------|----|-------|----|-------|-----|-------|
| 0 | 32 | 27 | 80.6 | 54 | 129.2 | 81 | 177.8 |
| 1 | 33.8 | 28 | 82.4 | 55 | 131 | 82 | 179.6 |
| 2 | 35.6 | 29 | 84.2 | 56 | 132.8 | 83 | 181.4 |
| 3 | 37.4 | 30 | 86.0 | 57 | 134.6 | 84 | 183.2 |
| 4 | 39.2 | 31 | 87.8 | 58 | 136.4 | 85 | 185 |
| 5 | 41 | 32 | 89.6 | 59 | 138.2 | 86 | 186.8 |
| 6 | 42.8 | 33 | 91.4 | 60 | 140 | 87 | 188.6 |
| 7 | 44.6 | 34 | 93.2 | 61 | 141.8 | 88 | 190.4 |
| 8 | 46.4 | 35 | 95 | 62 | 143.6 | 89 | 192.2 |
| 9 | 48.2 | 36 | 96.8 | 63 | 145.4 | 90 | 194 |
| 10 | 50 | 37 | 98.6 | 64 | 147.2 | 91 | 195.8 |
| 11 | 51.8 | 38 | 100.4 | 65 | 149 | 92 | 197.6 |
| 12 | 53.6 | 39 | 102.2 | 66 | 150.8 | 93 | 199.4 |
| 13 | 55.4 | 40 | 104 | 67 | 152.6 | 94 | 201.2 |
| 14 | 57.2 | 41 | 105.8 | 68 | 154.4 | 95 | 203 |
| 15 | 59 | 42 | 107.6 | 69 | 156.2 | 96 | 204.8 |
| 16 | 60.8 | 43 | 109.4 | 70 | 158 | 97 | 206.6 |
| 17 | 62.6 | 44 | 111.2 | 71 | 159.8 | 98 | 208.4 |
| 18 | 64.4 | 45 | 113 | 72 | 161.6 | 99 | 210.2 |
| 19 | 66.2 | 46 | 114.8 | 73 | 163.4 | 100 | 212 |
| 20 | 68 | 47 | 116.6 | 74 | 165.2 | | |
| 21 | 69.8 | 48 | 118.4 | 75 | 167 | | |
| 22 | 71.6 | 49 | 120.2 | 76 | 168.8 | | |
| 23 | 73.4 | 50 | 122 | 77 | 170.6 | | |
| 24 | 75.2 | 51 | 123.8 | 78 | 172.4 | | |
| 25 | 77 | 52 | 125.6 | 79 | 174.2 | | |
| 26 | 78.8 | 53 | 127.4 | 80 | 176 | | |

| Comparative Thermometric Scale | | | |
|---------------------------------|-----------------|-----------------|--------------|
| | Centi- grade | Fahren- heit | Reau- mur |
| Boiling point of water ... | 100° | 212° | 80° |
| | 90° | 194° | 72° |
| | 80° | 176° | 64° |
| | 70° | 158° | 56° |
| | 60° | 140° | 48° |
| | 50° | 122° | 40° |
| | 40° | 104° | 32° |
| | 30° | 86° | 24° |
| | 20° | 68° | 16° |
| | 10° | 50° | 8° |
| Freezing point of water | 0° | 32° | 0° |
| | —10° | 14° | —8° |
| | —20° | 4° | —16° |
| | | | |

CONVERSION: *F.* to *Centigrade*: Subtract 32 and multiply by 5/9. *C.* to *Fahrenheit*: Multiply by 9/5 and add 32. To convert *R.* into *F.* multiply by 9, divide by 4, and add 32.

There are 3 major scales, Centigrade, Fahrenheit, and Reaumur in use. The Celsius, no longer used, was the reverse of the *Centigrade*, zero being its boiling point. The *absolute scale*, used for only very low temperatures, based on absolute zero, the point at which the form of motion constituting heat ceases, —459.4° *F.*

SOURCE: *Taber's Cyclopedic Medical Dictionary*, Davis, 1957.

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